times when the condition is well-developed a fine rain falls covering everything with a coat of glaze ice.

At such times an examination of the weather map shows we are to the north of the axis of a trough of low pressure and that but a little way south of us warm west to southwest winds are blowing and no doubt overriding this cold northerly air, producing the clouds and sometimes rain. As a rule this condition is followed by a shift of wind to SW. and a rapid rise in temperature, the clouds all disappearing.

BOUNDARY BETWEEN A SOUTH WIND AND AN UNDERRUNNING NORTHEAST WIND.[1]

By CHARLES F. BROOKS.

[Blue Hill Observatory, Mass., May, 1913.]

In the late afternoon and evening of May 3, 1913, an anticyclone began to approach Blue Hill from the north. During the day a sea-breeze of three hours' duration had prevented the maximum temperature (80°F.) from occurring until the middle of the afternoon at the summit of the hill (195 m.). The wind remained in a southerly direction till 9 p. m. with momentary exceptions, marked by sharp drops in the thermograph curve.

The wind at the base station (64 m.) became northeast at 5:20 p. m. and therefore for several hours a considerable temperature inversion existed between the base and summit, at one time amounting to 14°F. At 7 p. m. the dividing line between the northeast wind and the south-southeast wind was across the summit of the hill in an east-west direction. This line was very sharp, so sharp that I could stand with the breeze from the northeast blowing on one cheek and that from the south on the other. At this time, as shown by the oscillations of the hygrograph curve up and back again whenever a small volume of northeast wind blew through the instrument shelter, the relative humidity on the dividing line was 80 per cent on one side (northeast) and 40 per cent on the other (south).

With the normal evening cooling the humidity presently reached 100 per cent on the dividing zone, thereby producing a fog. The pressure began its rapid rise at this time. Before long the stratus cloud rose from the top of the hill (3 a. m., by hygrograph), and by 7 a. m., May 4, was some distance above, its appearance giving an inverse "mammato" effect. At about noon the sun first broke through the cloud sheet, and by sundown most was gone.

(NOTE.—Another occasion on which I observed a similar sharp dividing line between winds from two directions was on July 25, 1912 near the Schilthorn, Switzerland. In the late afternoon, when there were thunderstorms in the vicinity, a cloudy current coming up the south side of a ridge on the east met a clear current up the north side with the result that a vertical cloud wall perhaps 100 meters high was formed.)

[1] *See* C. F. Brooks, Three ice storms, *Science*, Aug. 8, 1913, pp. 193-194, for descriptions of somewhat similar conditions.

THE PRECIPITATION OF SLEET AND THE FORMATION OF GLAZE IN THE EASTERN UNITED STATES, JANUARY 20 TO 25, 1920, WITH REMARKS ON FORECASTING.

By C. LEROY MEISINGER.

[Weather Bureau, Washington, D. C., Mar. 29, 1920.]

SYNOPSIS.

An attempt is made, by means of accurate charts of precipitation during the previous 12 hours, current temperature, pressure, and lines of wind flow, in combination with such aerological data as could be obtained, to construct cross-sections of the lower 3 kilometers of the atmosphere, during the period January 20 to 25, 1920. From such charts are shown the actual processes which produce rain, sleet, and snow, separately and in combination, in such a manner as to produce the ice cover, which is called an "ice storm." The condition is, briefly, a cold northerly wind underrunning a warm southerly current, forcing the latter aloft. The vertical distribution of temperature, shown in the cross-sections, indicates the manner in which the isotherms in that territory covered by the northerly wind rise normally until the level of the overrunning southerly wind is attained, where the isotherm swerves sharply northward. The distance that the isotherm of freezing reaches is indicated by the northern limit of the precipitation of sleet.

An empirical relation was obtained between the distance from the wind-shift line to the 32° isotherm and (1) the width of the glaze belt, (2) the width of the sleet belt, (3) the distance of the center of the sleet belt north of the 32° isotherm, (4) the width of the glaze belt on a meridian 4° east 12 hours later, and (5) the width of the glaze belt on a meridian 8° east 24 hours later. These values are presented with the full realization that they may be true for this particular storm only, and are as follows:

(1) The width of the glaze belt=the distance between the 32° isotherm and the wind-shift line;

(2) The width of the sleet belt=0.7 × the distance between the 32° isotherm and the wind-shift line;

(3) The distance between the 32° isotherm and the center of the sleet belt=0.8 × the distance between the 32° isotherm and the wind-shift line;

(4) The width of the glaze belt 4° east, 12 hours later=0.9 × the distance between the 32° isotherm and the wind-shift line; and,

(5) The width of the glaze belt 8° east, 24 hours later=0.8 × the distance between the 32° isotherm and the wind-shift line.

The importance of the wind-shift line in forecasting the region over which sleet or glaze are likely to occur is strongly emphasized, since it marks the point of ascent of the southerly wind and hence is the basis upon which rests the location of this type of precipitation.

INTRODUCTION.

Of all types of storms, there are few which have the wide-spread economic effects of the so-called "ice storm." Not only is traffic, both on railroads and in cities, impeded and often completely tied up, and telephone and telegraph lines crippled, but accidents are numerous also. Moreover, when rain falls on a region previously covered with snow and produces an ice glaze, the snow is held immovable and the glaze forms a gliding surface over which subsequent snow will drift with little hindrance. In New York City recently, when the streets were more effectually blockaded by snow than at any time in the city's history, not a small part of the difficulty in its removal was attributable to the fact that there had been layers of ice formed at various levels in the snow, increasing the rigidity of the drifts and packing them more solidly.

Often such storms are local and do not have a widespread effect, but once or twice in a winter they occur over a large area of the country. They are caused, of course, simply by the precipitation of rain upon a region the temperature of which is at freezing or below. In many cases, it is not long before all surfaces exposed to the rain become heavily coated with a crystal-clear layer of ice, sometimes as much as an inch in thickness. This type of storm has been called by the rather unsatisfactory name of *ice storm.* The ice cover which is formed is called by the English *glazed frost;* this is not satisfactory because it is not related to frost; the French *verglas* and the German *Glatteis* are more descriptive. Our word *glaze,* adopted by the Weather Bureau in 1916, comes nearest to a satisfactory designation for this condition.[1]

The conditions under which such precipitation is produced have been discussed in the preceding article by Dr. C. F. Brooks,[2] and the reader is referred to his article for an explanation of the processes taking place aloft which produce areas of snow, sleet, glaze, and rain, either singly or in combination. This paper proposes to discuss, as far as available data and legitimate speculation will permit, the conditions aloft as well as at the surface, and to show how they interact in a specific storm.

PLAN OF THE STUDY.

The winter of 1919–20 has been a particularly unpleasant one in the Eastern United States, owing, especially, to the great precipitation of snow in the northern portions, and of snow, sleet, and rain in the middle latitudes, which formed a solid, slow-melting cover. Perhaps the worst periods of this type were those of January 20–25 and February 3–6, the former covering practically all the territory east of the 100th meridian, while the latter was confined to the Atlantic coast States. The first period has been investigated the more thoroughly owing to its greater area and duration.

Forecasting.—The forecasting of sleet and glaze is very difficult because they occur so rarely that it is hard to sort out from the complex of the weather those conditions which so combine and operate as to produce this effect 12 to 24 hours later. The following conditions, according to Prof. H. C. Frankenfield, in "Weather Forecasting in the United States,"[3] are usually productive of sleet storms and glaze formation:

1. Low temperature and high pressure to the northward (between northwest and northeast.) * * *
2. Steep pressure and temperature gradients to the northward (between northwest and northeast.) * * *
3. Surface temperatures below freezing. * * *
4. Moderately high pressure and high temperature over the East Gulf and South Atlantic States. * * *
5. Northward looping of the isotherms. * * *
6. Gentle to fresh northerly winds, increasing by time sleet begins. * * *
7. Low pressure trough trending southwest to northeast between two HIGHS. The LOW is usually moving from the southwest, but sometimes from the northwest.

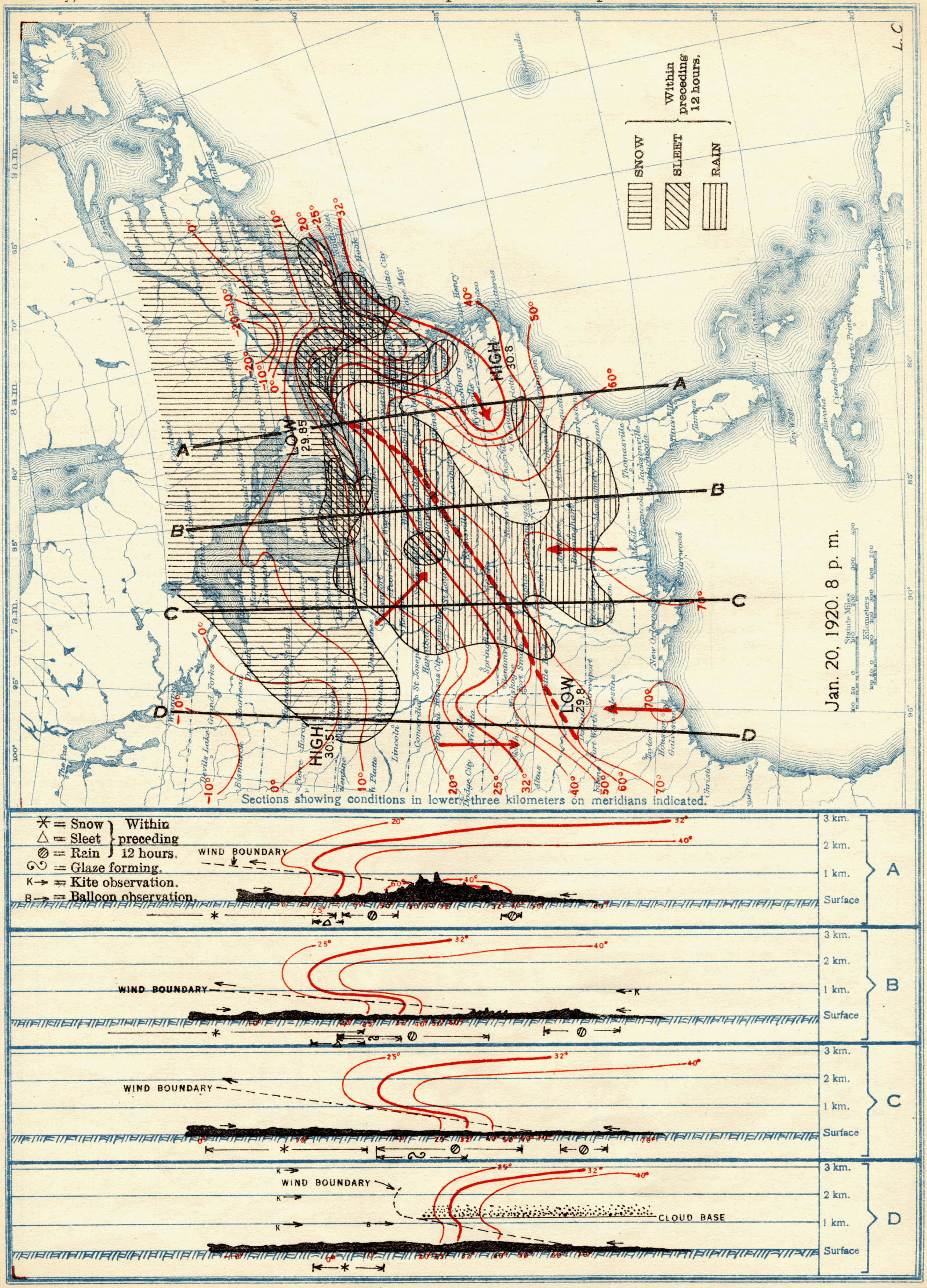
And, while it is possible, when such formations are present, to say that *sleet will occur* or that *glaze will occur,* it is rarely possible to forecast its location more definitely than to designate its center. But the width of the area is, obviously, a function of the temperature both at the surface and aloft, and of the strength of the north and south components of the underrunning and overriding winds. Even though the critical examination of a single storm is unlikely to shed as much light on these relationships as might be desired, nevertheless, such an investigation justifies itself in setting forth clearly throughout the period the conditions which did prevail together with the kind of precipitation and the regions over which it occurred.

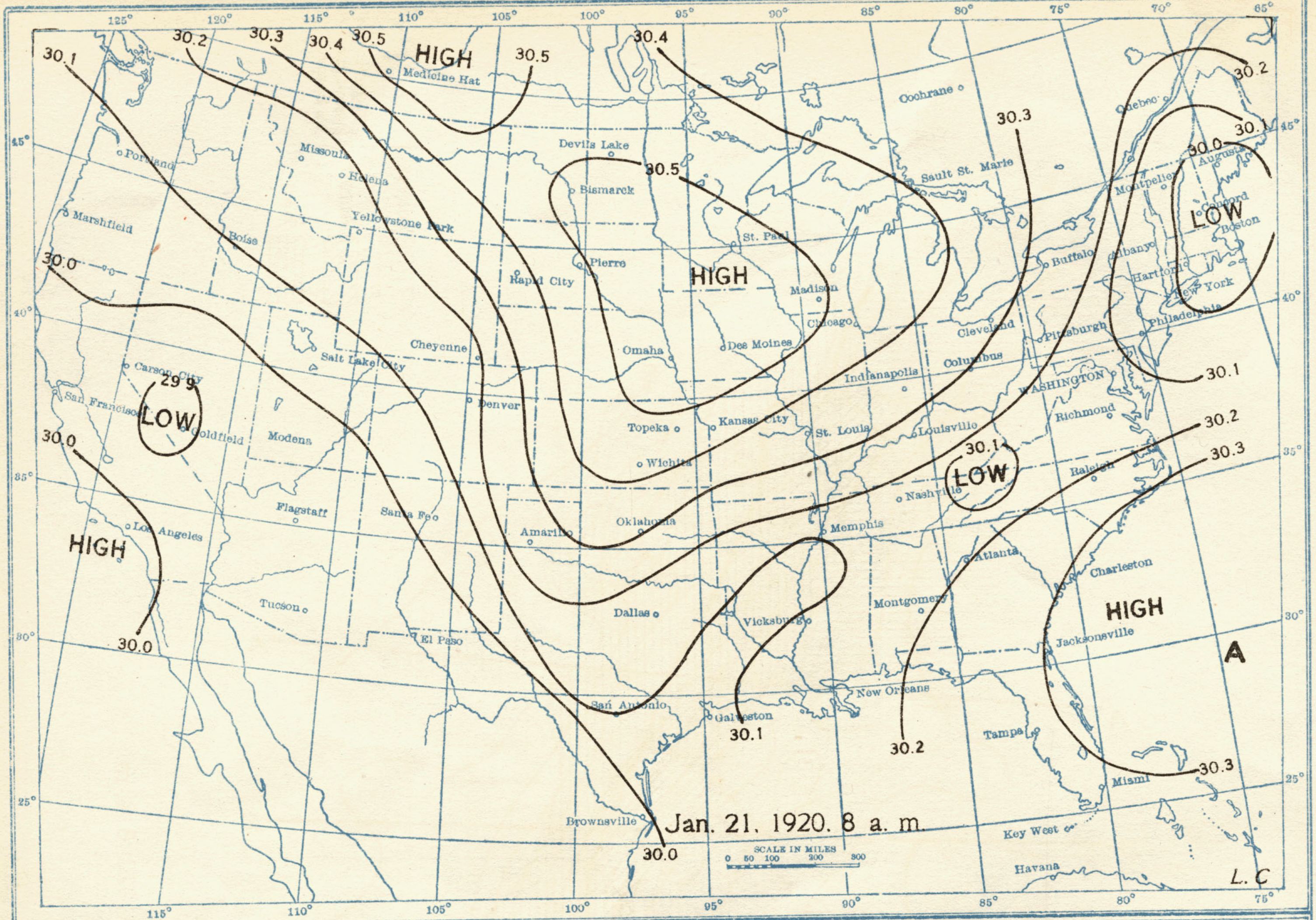
Meridional sections of the atmosphere.—Besides the ordinary relations of barometric pressure and precipitation, it is necessary to investigate by means of meridional cross-sections the distribution of temperature, cloudiness, and wind velocity aloft; also to construct maps showing the areas over which precipitation in the form of rain, sleet, or snow, or combinations of these, occurred. In constructing the meridional cross-sections two assumptions are necessary—first, that the wind of southerly component continues aloft after leaving the ground, overriding the wind of northerly component; and, second, that the temperature of the wind of southerly component may be surmised from the following: (*a*) The temperature fall per degree of latitude as the southerly wind proceeds northward can give a clue as to the temperature of the wind after it has risen from the surface; (*b*) the dynamic cooling of the southerly air as it rises can be surmised from the amount of precipitation; (*c*) the northern limit of the isotherm of freezing is marked, with due consideration for the effect of wind velocity in keeping the sleet pellets and raindrops from falling vertically, by the northern limit of sleet or rainfall; and (*d*) the motion, type, and height of the base of the clouds tell much concerning the conditions aloft, where kite observations are wanting.

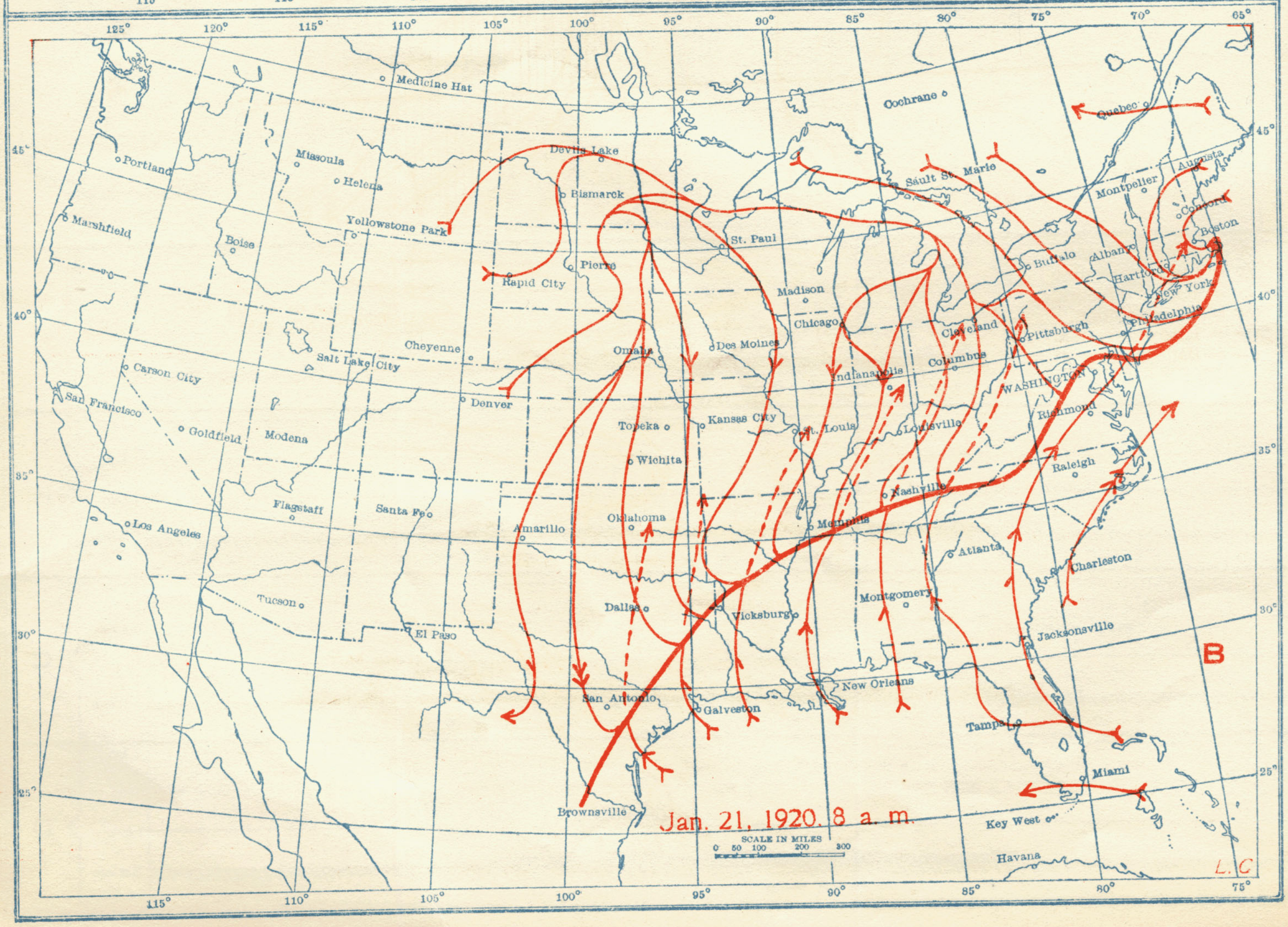
Width of sleet and glaze belts.—The width of the sleet belt and glaze belt are, of course, of prime importance in the forecast, and thus the forecast becomes primarily one of temperature; i. e., the predicting as accurately as possible the location of the horizontal freezing line. But while this can be a certain guide to the general location of sleet and glaze, there must be other conditions peculiar to the winds involved which will determine the width of the area over which precipitation will occur. At the outset the following considerations were suggested: (1) The steepness of the surface temperature gradient within the zone of northerly winds; (2) the strength of the southward component in the northerly winds; (3) the strength of the southerly wind aloft; (4) the difference between the surface temperature and the maximum temperature aloft; and (5) the determination of the height of the maximum temperature aloft. The last point is one that is subject to several considerations. If one considers the surface temperature in the southerly wind at some point south of the wind-shift line, or the line where the southerly component disappears and the northerly appears, it is possible to approximate the altitude of the freezing temperature by assuming an appropriate vertical temperature gradient, dependent upon the current conditions. Direct observation by kites is desirable, but where this is impossible, the current conditions can be surmised by allowing the vertical temperature gradient to depart from the normal shown by kites in accordance with the variation of other conditions from the normal, such as wind speed and snow cover. Again, after this southerly current leaves the ground its temperature must be dynamically lowered. Finally, the strength of the southerly component must be considered, for it is apparent that an increase of wind velocity with altitude, when the wind is bearing a temperature very high relative to that at the surface, is certain to carry the warm air farther north over the cold layer than would otherwise be the case. All of these three factors must be included in any speculation regarding the altitude of the freezing temperature at its northern extremity aloft.

Charts.—To aid in the discussion of the data from the various standpoints mentioned above, the accompanying series of charts has been devised. The even-numbered Charts II, IV, VI, etc., consist of two maps, the upper showing the sea-level pressure distribution, and the lower showing the instantaneous stream lines at the same time. The stream line map must not be misunder-

[1] Abbe, Cleveland, jr.: American definition of "sleet." MONTHLY WEATHER REVIEW 1916, 44: 281-286.
[2] Brooks, Charles F.: The nature of sleet and how it is formed. This REVIEW, pp. 69-72.
[3] U. S. Dept. of Agriculture, Weather Bureau: Weather forecasting in the United States, Washington, 1916, pp. 257-260.


SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 20, 1920. 8 p. m.
LOW 29.85
HIGH 30.8
LOW 29.8
HIGH 30.51
Statute Miles
Kilometers
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
= Glaze forming.
K→ = Kite observation.
B→ = Balloon observation.
WIND BOUNDARY
CLOUD BASE
3 km.
2 km.
1 km.
Surface
A
B
C
D


HIGH
HIGH
HIGH
HIGH
LOW
LOW
LOW
29.9
30.0
30.1
30.2
30.3
30.4
30.5
Medicine Hat
Devils Lake
Bismarck
Cochrane
Sault St. Marie
Quebec
Montpelier
Augusta
Concord
Boston
Portland
Missoula
Helena
Yellowstone Park
Marshfield
Boise
Rapid City
Pierre
St. Paul
Madison
Chicago
Buffalo
Albany
Hartford
New York
Philadelphia
Pittsburgh
Cleveland
Columbus
Indianapolis
Omaha
Des Moines
Cheyenne
Salt Lake City
Carson City
San Francisco
Goldfield
Modena
Denver
Topeka
Kansas City
St. Louis
Louisville
WASHINGTON
Richmond
Wichita
Raleigh
Nashville
Flagstaff
Santa Fe
Amarillo
Oklahoma
Memphis
Los Angeles
Atlanta
Charleston
Tucson
Dallas
Vicksburg
Montgomery
El Paso
Jacksonville
San Antonio
Galveston
New Orleans
Tampa
Miami
Brownsville
Key West
Havana
Jan. 21, 1920. 8 a. m.
SCALE IN MILES
A
L. C


Medicine Hat
Devils Lake
Bismarck
Cochrane
Sault St. Marie
Quebec
Augusta
Montpelier
Concord
Boston
Portland
Missoula
Helena
Yellowstone Park
Marshfield
Boise
Rapid City
Pierre
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Des Moines
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Louisville
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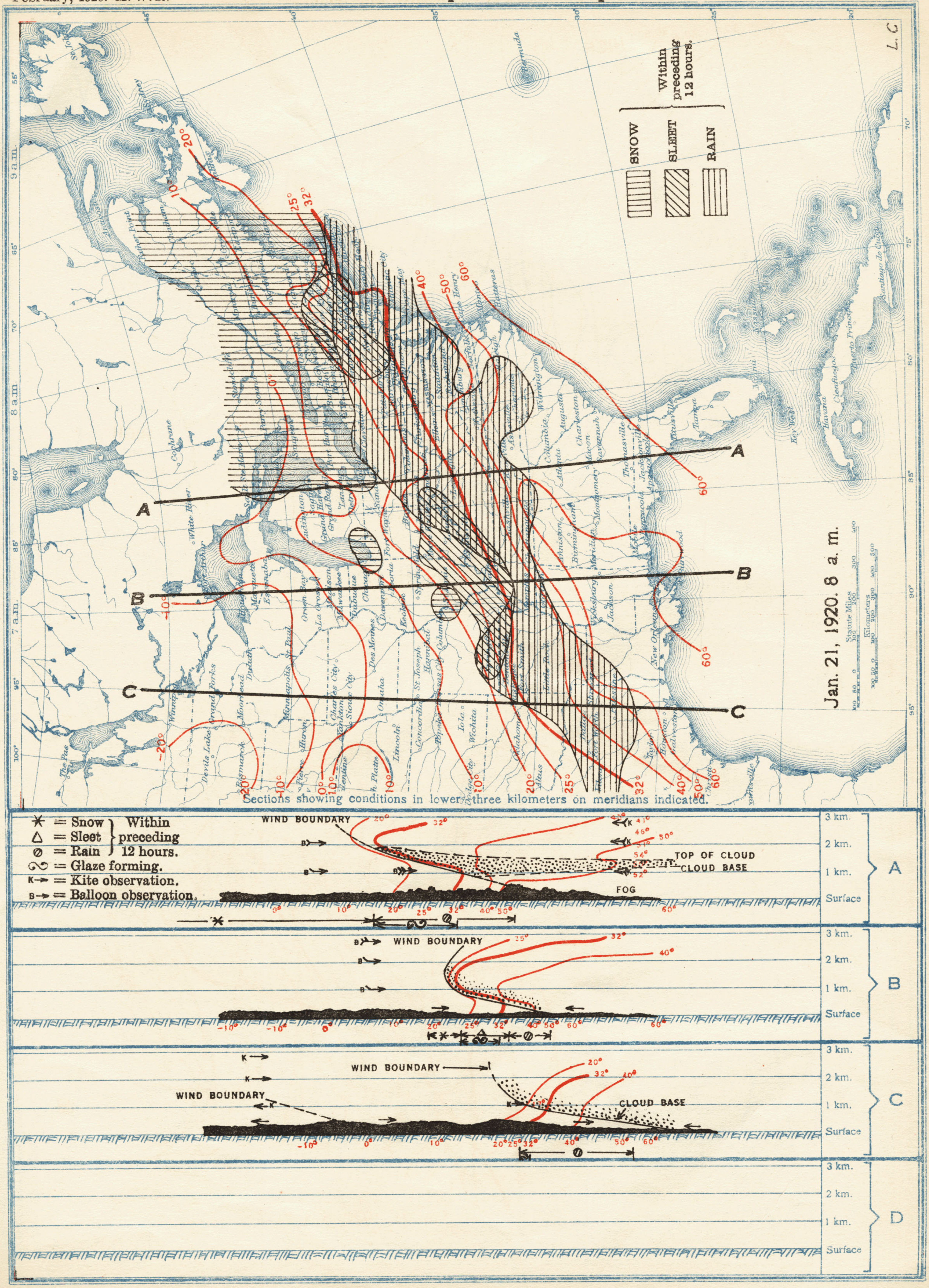
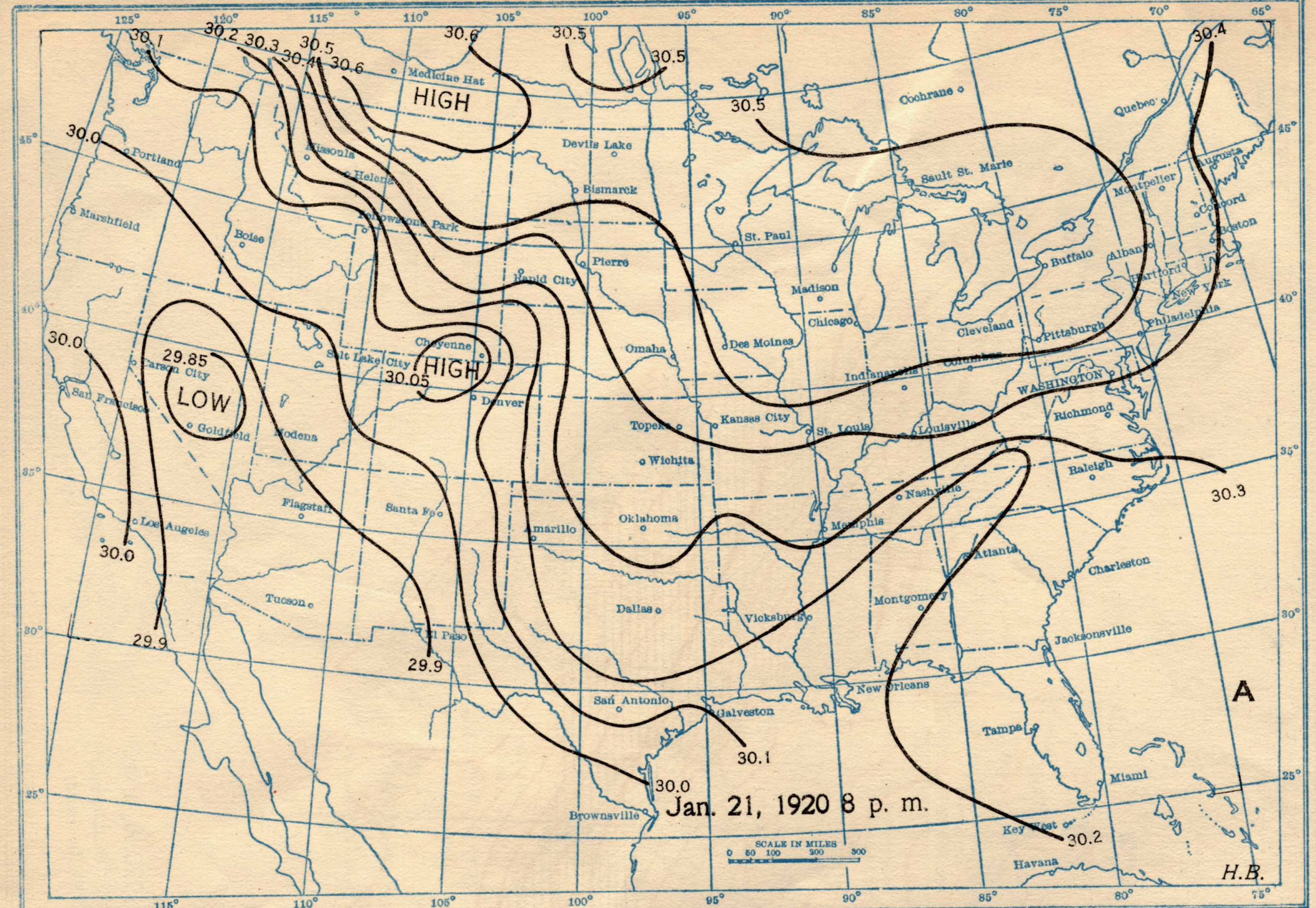
Charleston
Tucson
Dallas
Vicksburg
Montgomery
El Paso
Jacksonville
San Antonio
Galveston
New Orleans
Tampa
Miami
Brownsville
Key West
Havana
Jan. 21, 1920. 8 a. m.
SCALE IN MILES
B
L. C

Chart III. Precipitation and Temperature.




HIGH
HIGH
LOW
30.1
30.2
30.3
30.4
30.5
30.6
30.0
29.85
30.05
29.9
30.4
30.5
30.3
30.2
A
Jan. 21, 1920 8 p. m.
SCALE IN MILES
H.B.
Medicine Hat
Portland
Marshfield
Missoula
Helena
Yellowstone Park
Boise
Devils Lake
Bismarck
Pierre
Rapid City
Cheyenne
Salt Lake City
Denver
Carson City
San Francisco
Goldfield
Modena
Los Angeles
Flagstaff
Santa Fe
Tucson
El Paso
Amarillo
Oklahoma
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Des Moines
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Memphis
Dallas
Vicksburg
Montgomery
Atlanta
San Antonio
Galveston
New Orleans
Brownsville
Tampa
Miami
Key West
Havana
Jacksonville
Charleston
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WASHINGTON
Columbus
Cleveland
Pittsburgh
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Albany
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Philadelphia
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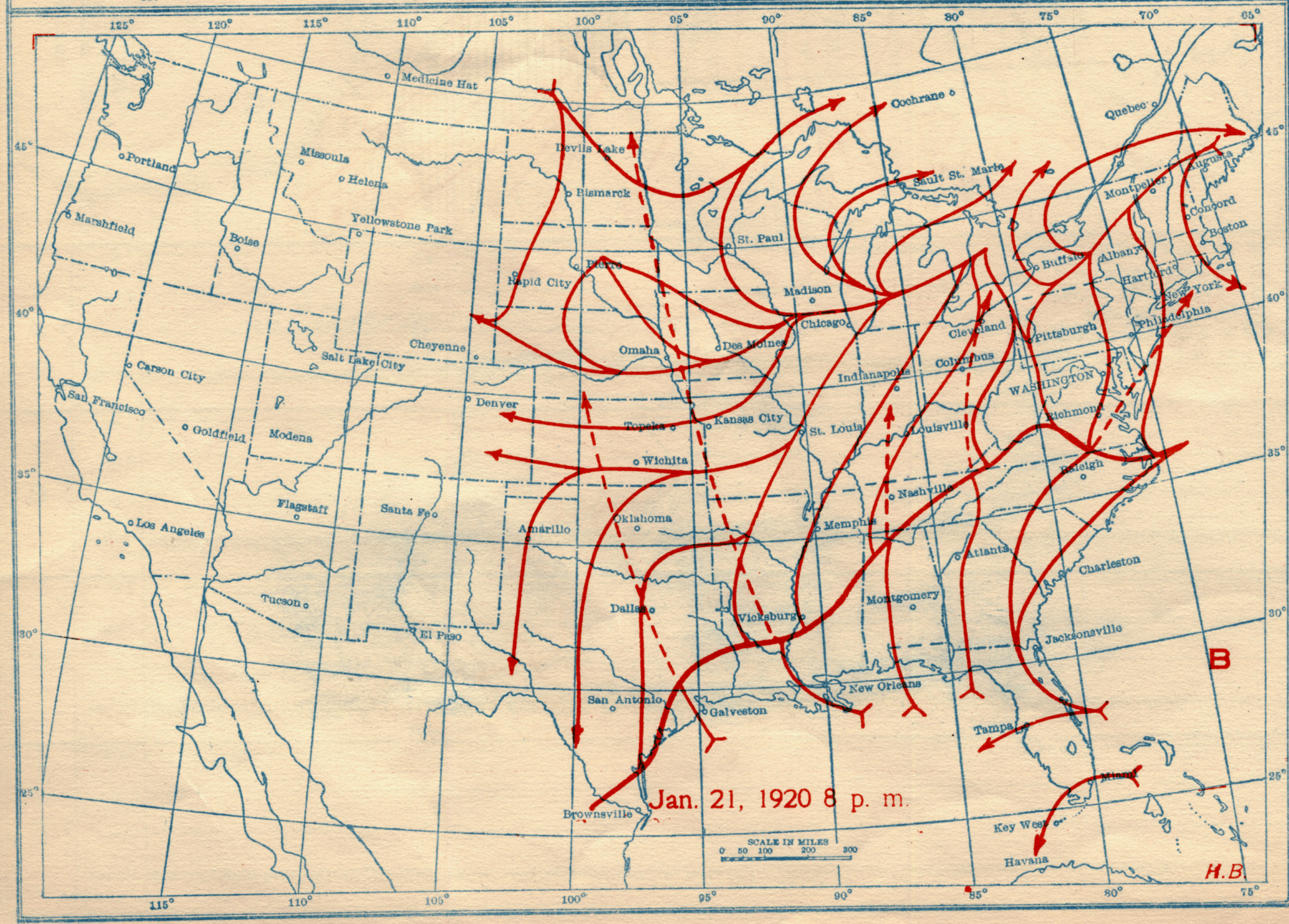
Concord
Augusta
Montpelier
Quebec
Cochrane
Sault St. Marie


B
Jan. 21, 1920 8 p. m.
SCALE IN MILES
H.B
Medicine Hat
Portland
Marshfield
Missoula
Helena
Yellowstone Park
Boise
Devils Lake
Bismarck
Pierre
Rapid City
Cheyenne
Salt Lake City
Denver
Carson City
San Francisco
Goldfield
Modena
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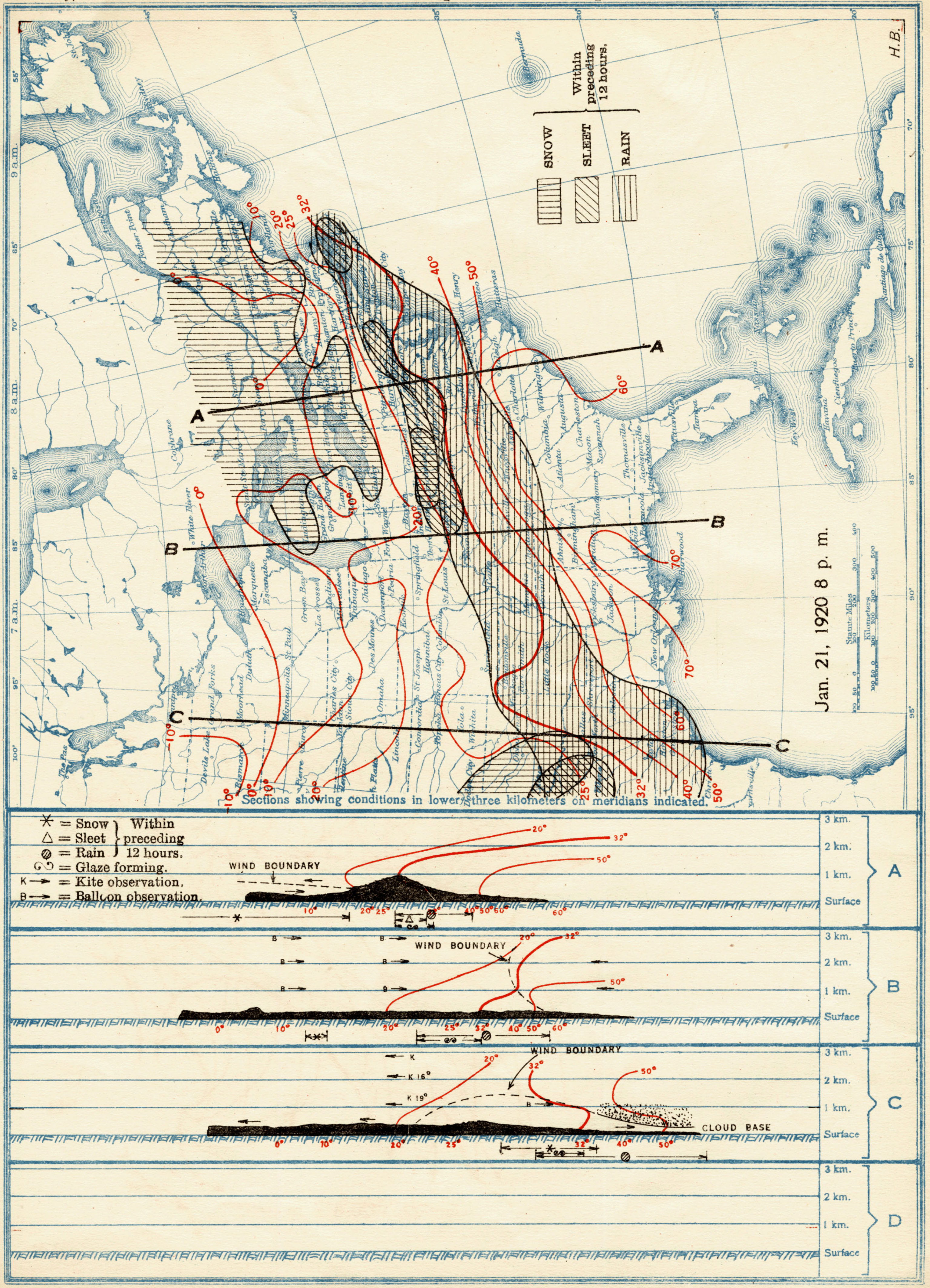
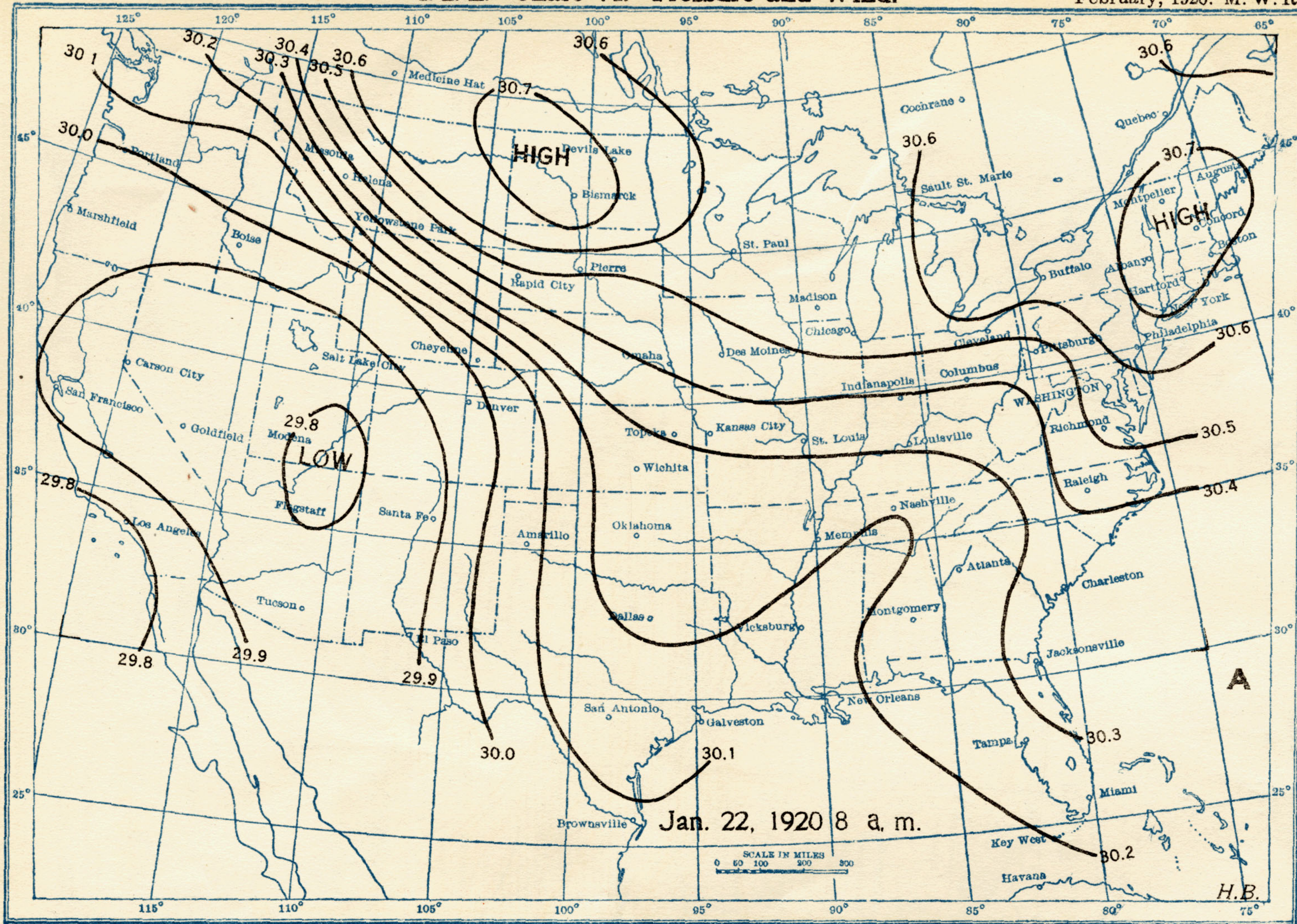
Quebec
Cochrane
Sault St. Marie


H.B.
SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 21, 1920 8 p. m.
Statute Miles
Kilometers
A
B
C
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
ꝏ = Glaze forming.
K → = Kite observation.
B → = Balloon observation.
WIND BOUNDARY
CLOUD BASE
3 km.
2 km.
1 km.
Surface
D


HIGH
HIGH
LOW
30.7
30.6
30.5
30.4
30.3
30.2
30.1
30.0
29.9
29.8
Medicine Hat
Cochrane
Quebec
Devils Lake
Bismarck
Missoula
Helena
Portland
Marshfield
Boise
Yellowstone Park
Sault St. Marie
Montpelier
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Amarillo
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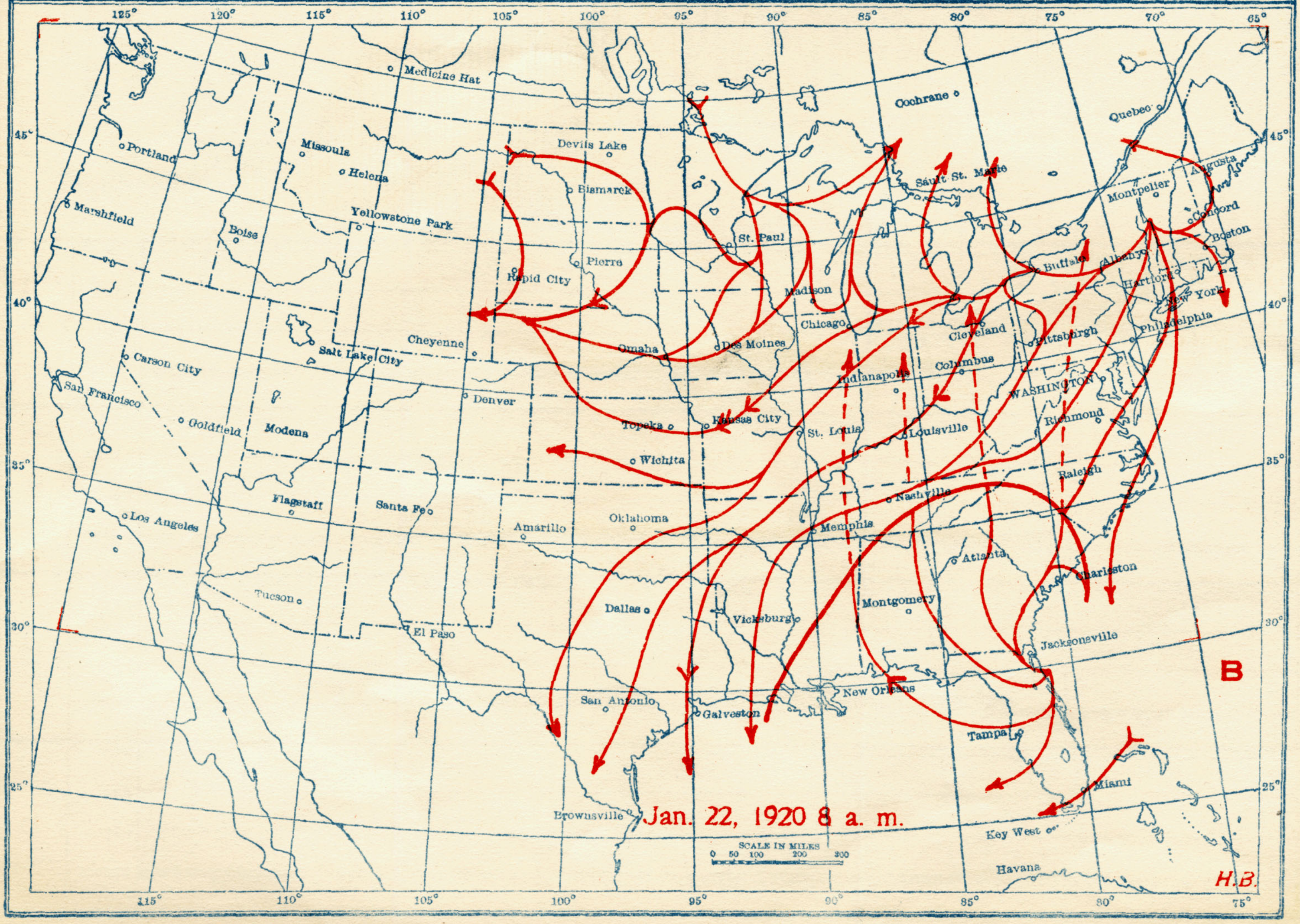
Atlanta
Charleston
Tucson
Dallas
Vicksburg
Montgomery
El Paso
Jacksonville
San Antonio
Galveston
New Orleans
Tampa
Miami
Brownsville
Key West
Havana
Jan. 22, 1920 8 a. m.
SCALE IN MILES
0 50 100 200 300
A
H.B.


Medicine Hat
Cochrane
Quebec
Devils Lake
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Marshfield
Yellowstone Park
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Salt Lake City
Carson City
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Kansas City
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Vicksburg
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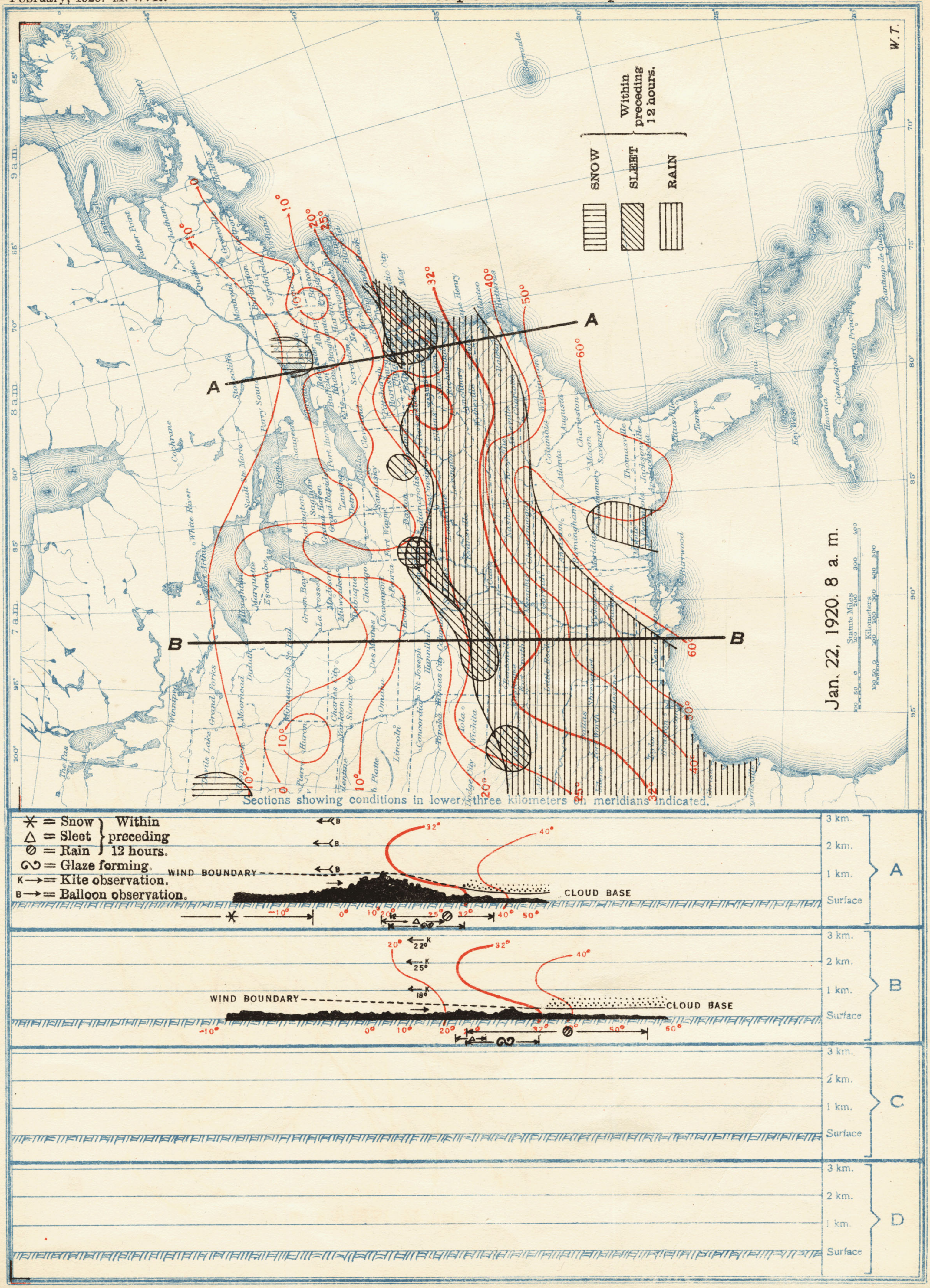
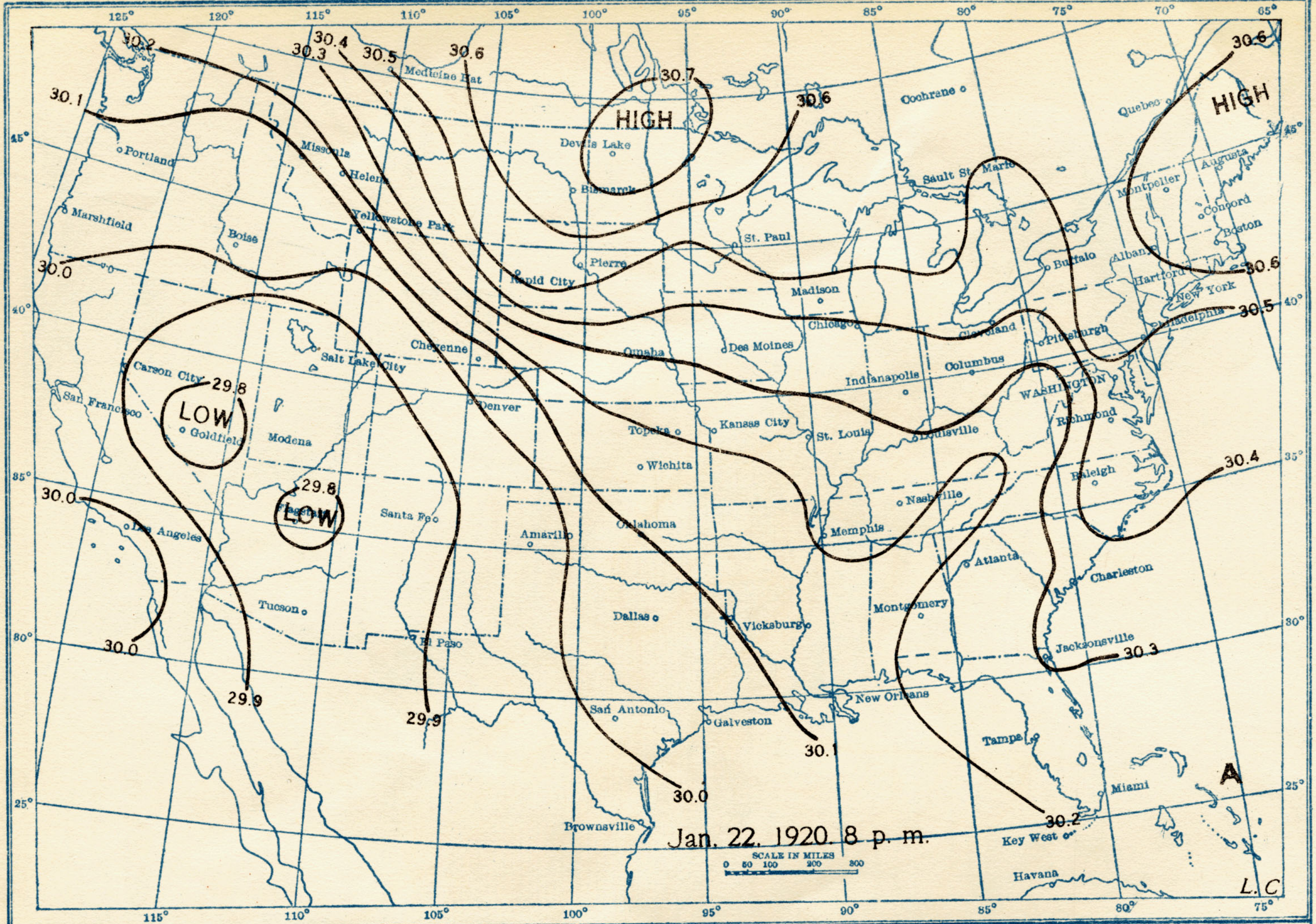
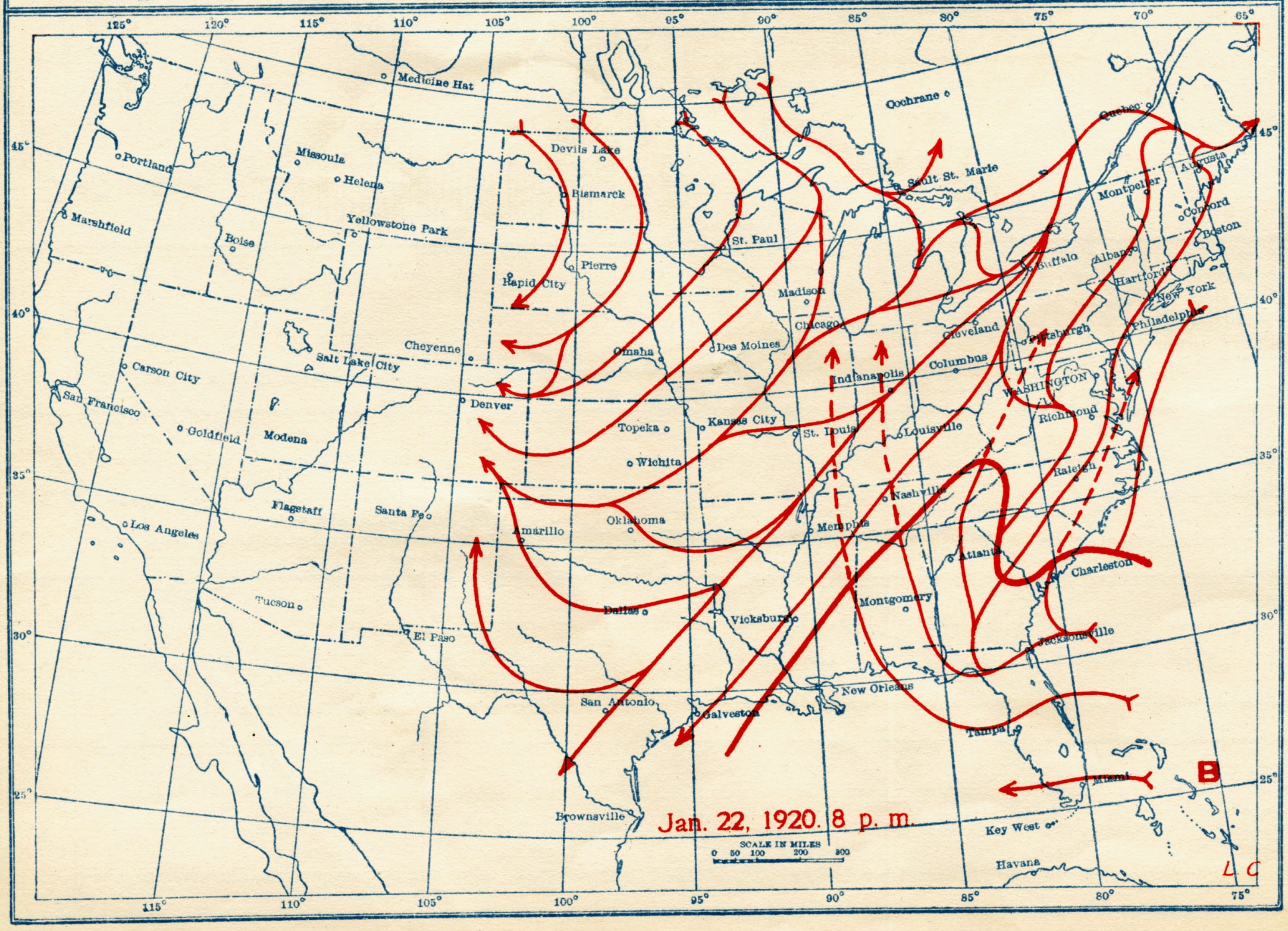
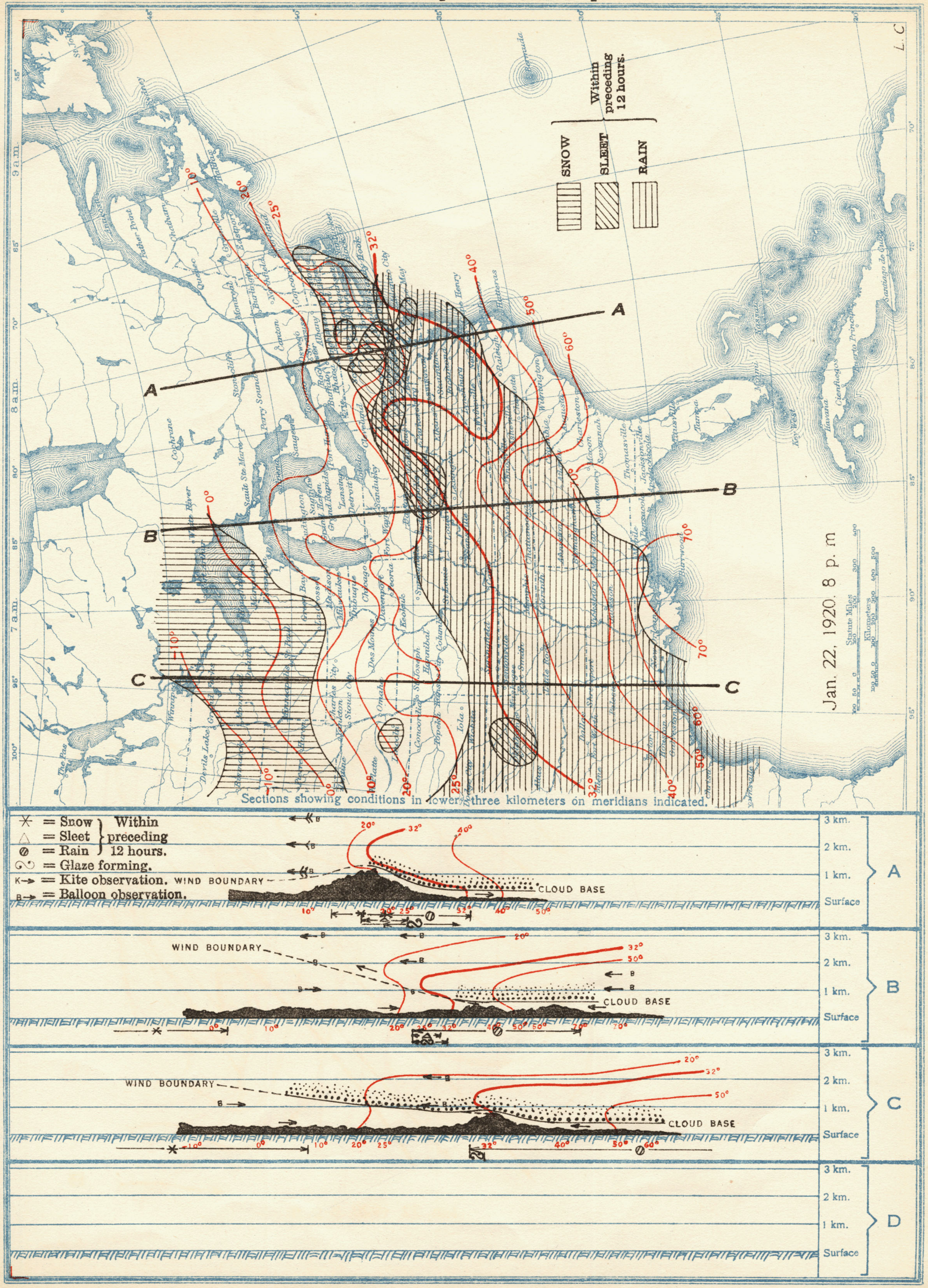
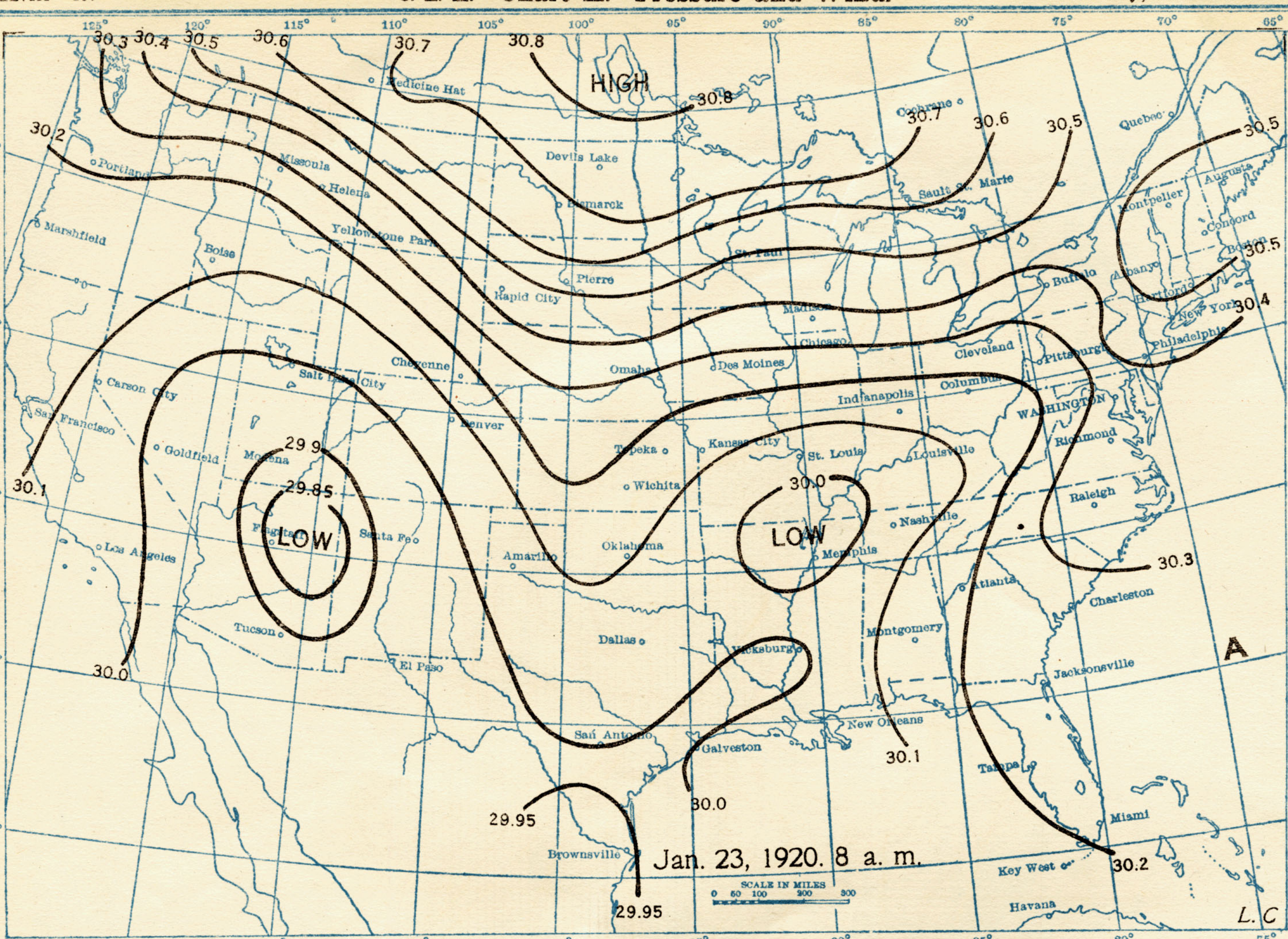
El Paso
Jacksonville
New Orleans
San Antonio
Galveston
Tampa
Miami
Brownsville
Key West
Havana
Jan. 22, 1920 8 a. m.
SCALE IN MILES
0 50 100 200 300
B
H.B.

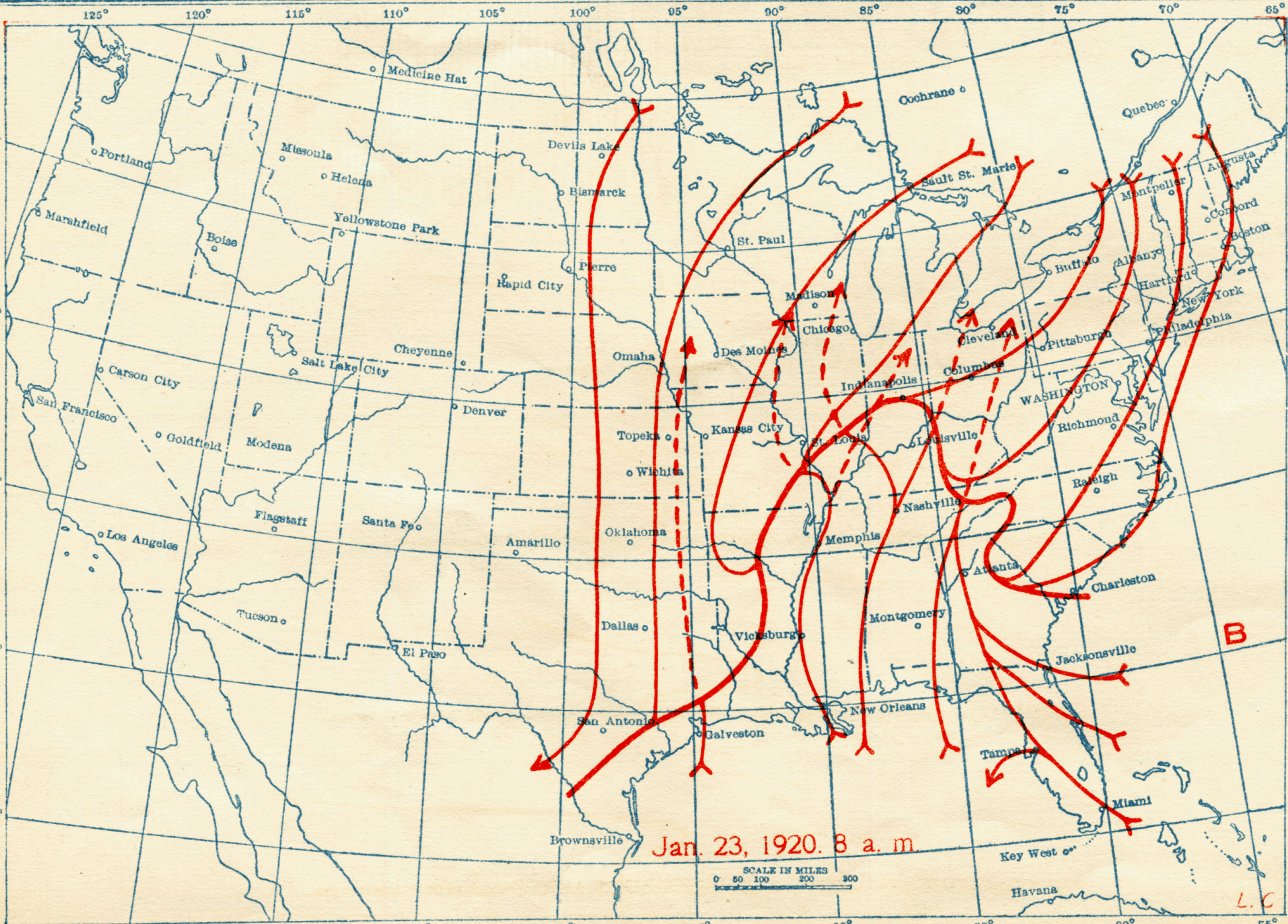

W. T.
SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 22, 1920. 8 a. m.
Statute Miles
Kilometers
A
B
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
Glaze forming.
K⟶ = Kite observation.
B⟶ = Balloon observation.
WIND BOUNDARY
CLOUD BASE
3 km.
2 km.
1 km.
Surface
C
D

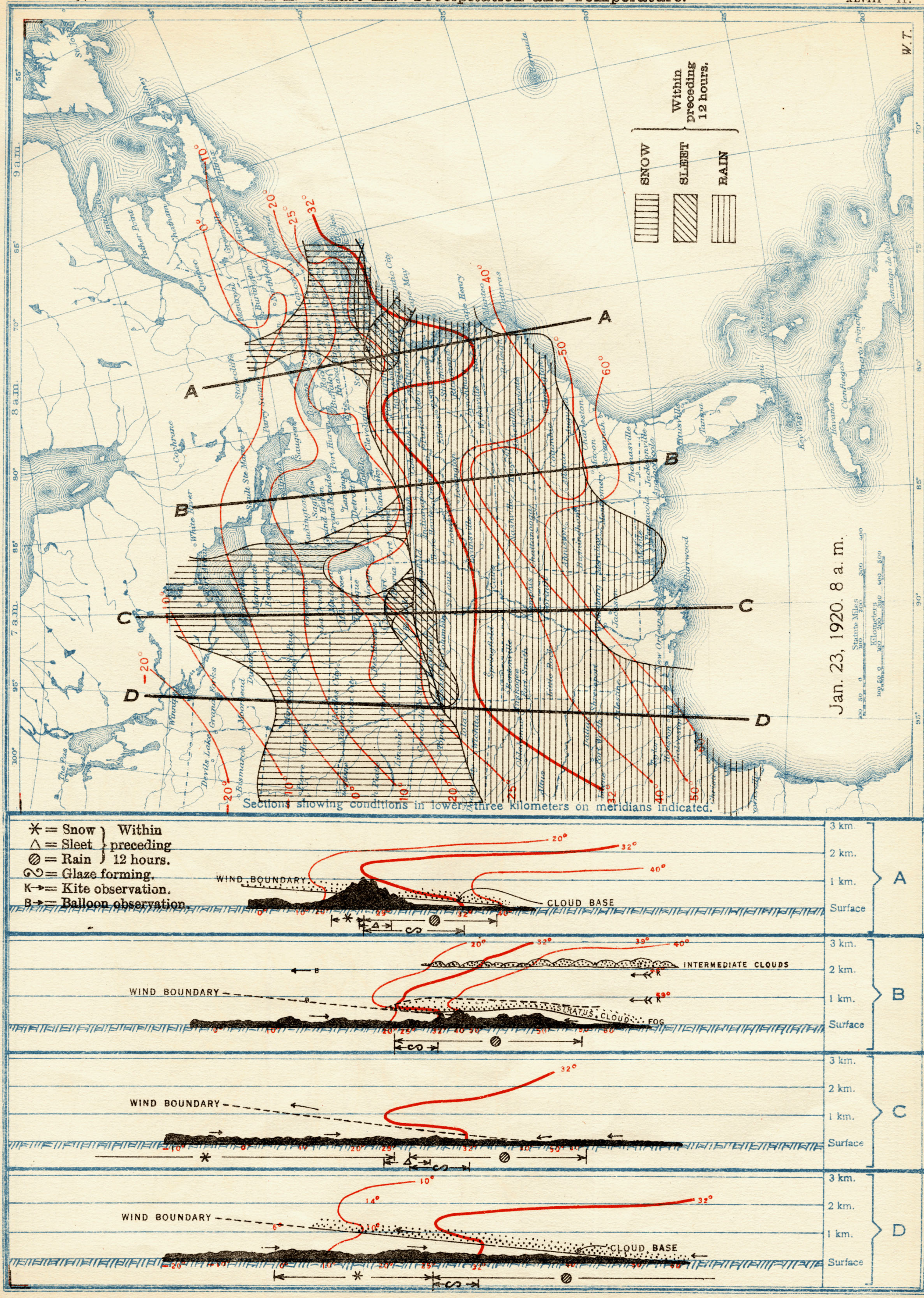

HIGH
HIGH
LOW
LOW
30.1
30.2
30.3
30.4
30.5
30.6
30.7
30.0
29.8
29.9
A
Jan. 22. 1920. 8 p. m.
SCALE IN MILES
L. C.

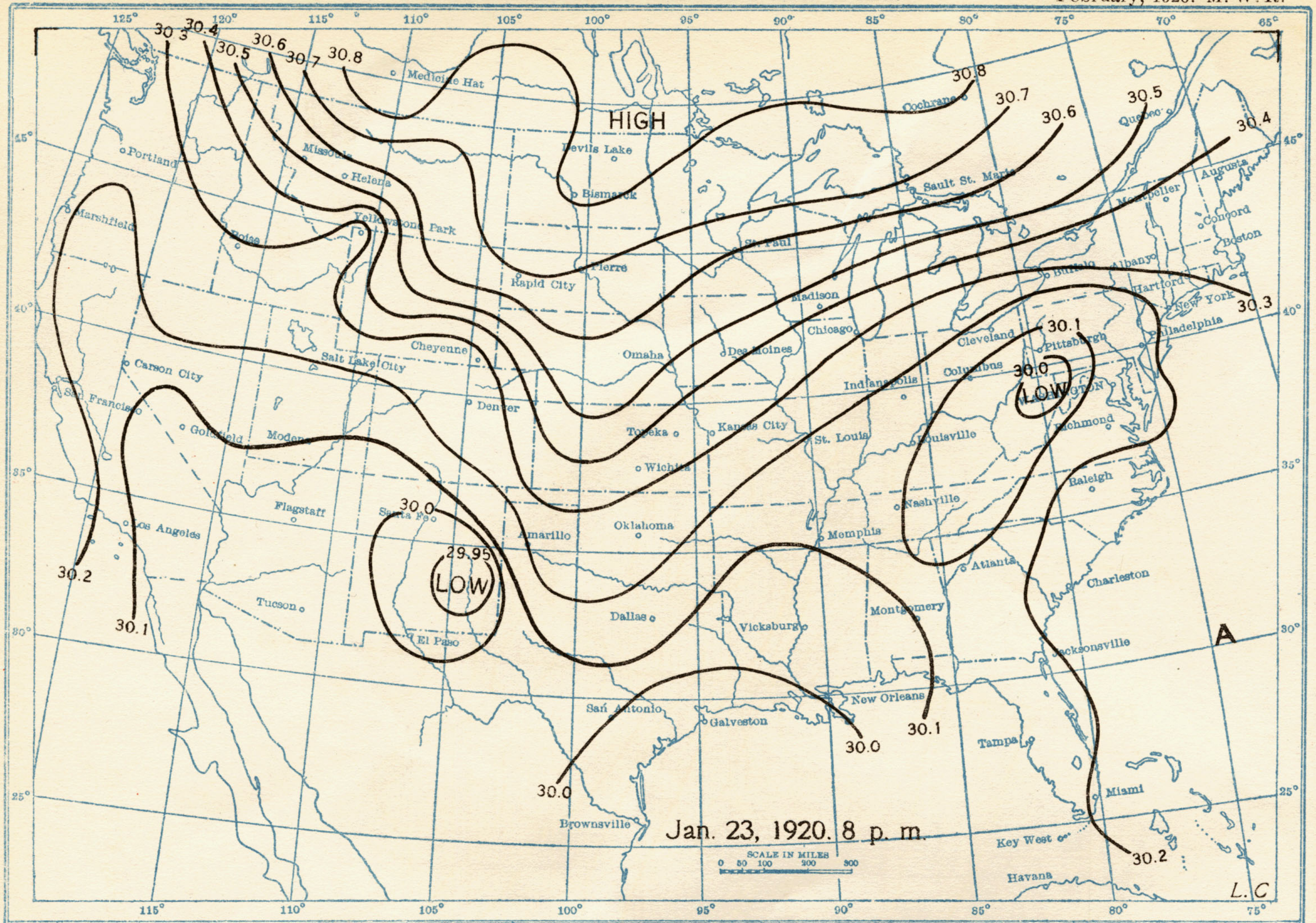

B
Jan. 22, 1920. 8 p. m.
SCALE IN MILES
L. C.


Within preceding 12 hours.
SNOW
SLEET
RAIN
Jan. 22, 1920. 8 p. m
Statute Miles
Kilometers
A
B
C
Sections showing conditions in lower three kilometers on meridians indicated.
= Snow
= Sleet
= Rain
Within preceding 12 hours.
= Glaze forming.
= Kite observation.
= Balloon observation.
WIND BOUNDARY
CLOUD BASE
3 km.
2 km.
1 km.
Surface
A
B
C
D


HIGH
LOW
LOW
30.3
30.4
30.5
30.6
30.7
30.8
30.2
30.1
30.0
29.9
29.85
29.95
A
Jan. 23, 1920. 8 a. m.
SCALE IN MILES
L. C


B
Jan. 23, 1920. 8 a. m.
SCALE IN MILES
L. C


W. T.
SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 23, 1920. 8 a. m.
A
B
C
D
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
= Glaze forming.
K→ = Kite observation.
B→ = Balloon observation.
WIND BOUNDARY
CLOUD BASE
INTERMEDIATE CLOUDS
STRATUS CLOUD
FOG
3 km.
2 km.
1 km.
Surface


HIGH
LOW
LOW
30.0
29.95
30.1
30.2
30.3
30.4
30.5
30.6
30.7
30.8
Medicine Hat
Cochrane
Quebec
Devils Lake
Bismarck
Portland
Missoula
Helena
Sault St. Marie
Montpelier
Augusta
Concord
Boston
Marshfield
Boise
Yellowstone Park
St. Paul
Pierre
Rapid City
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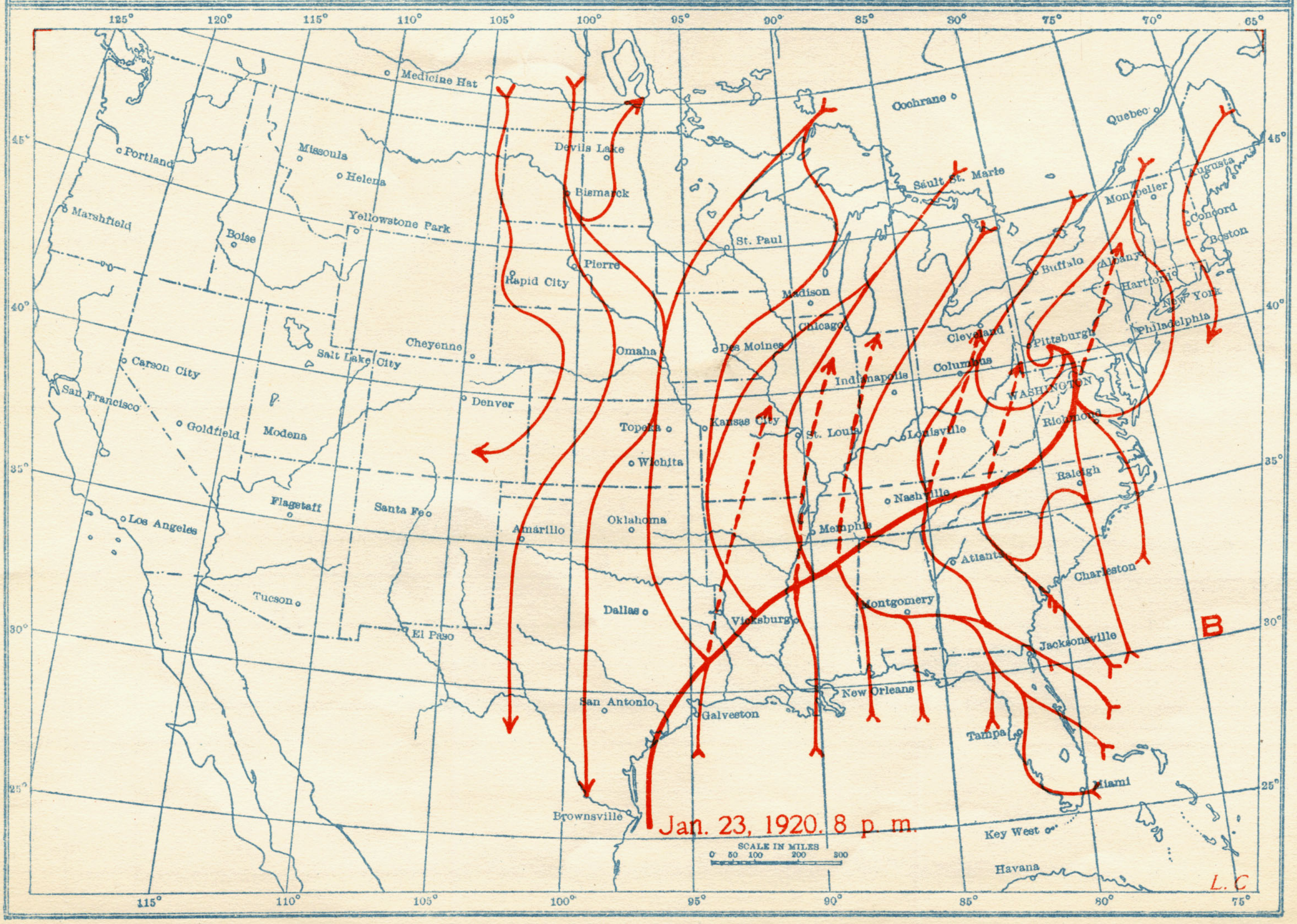
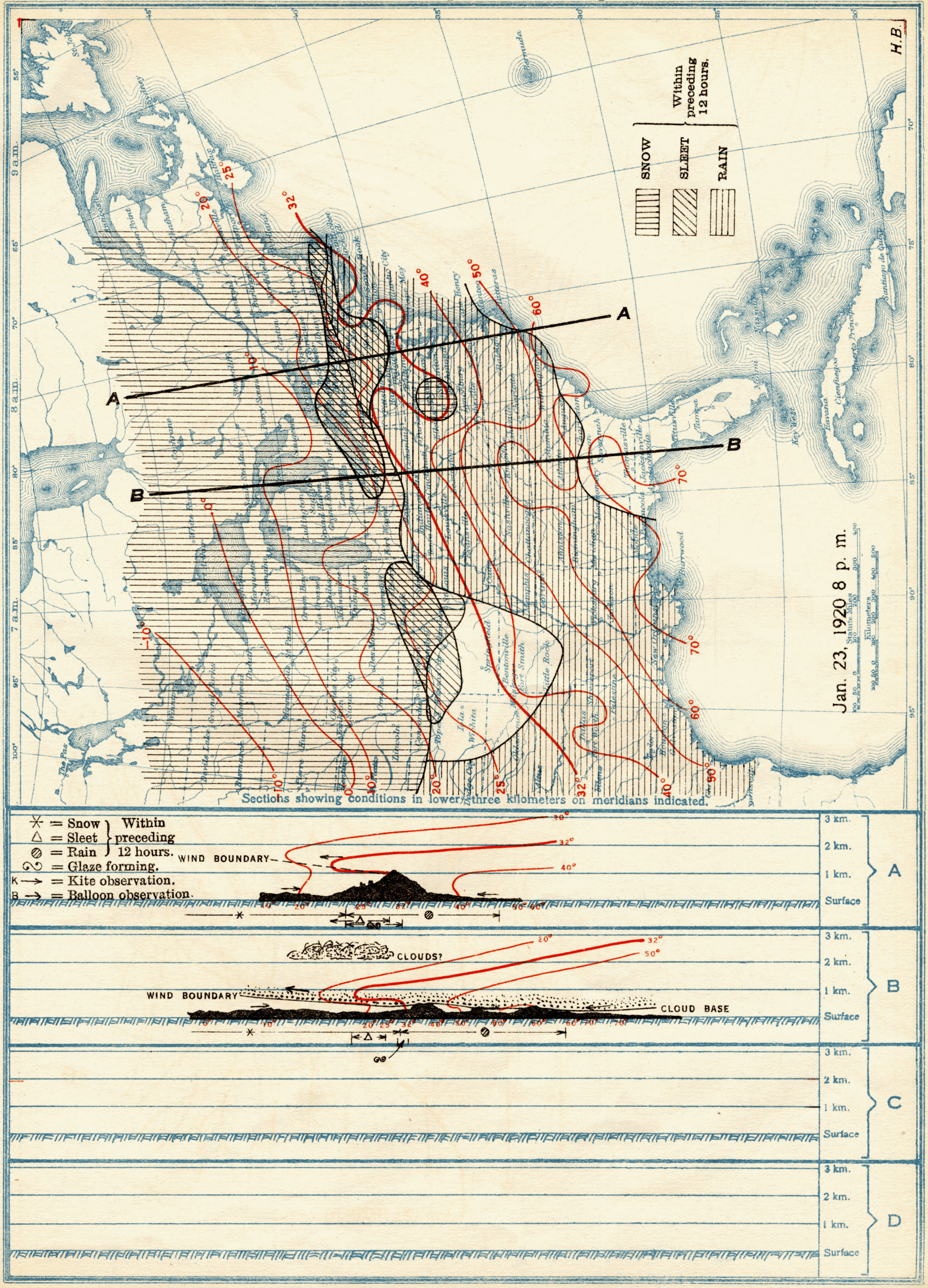
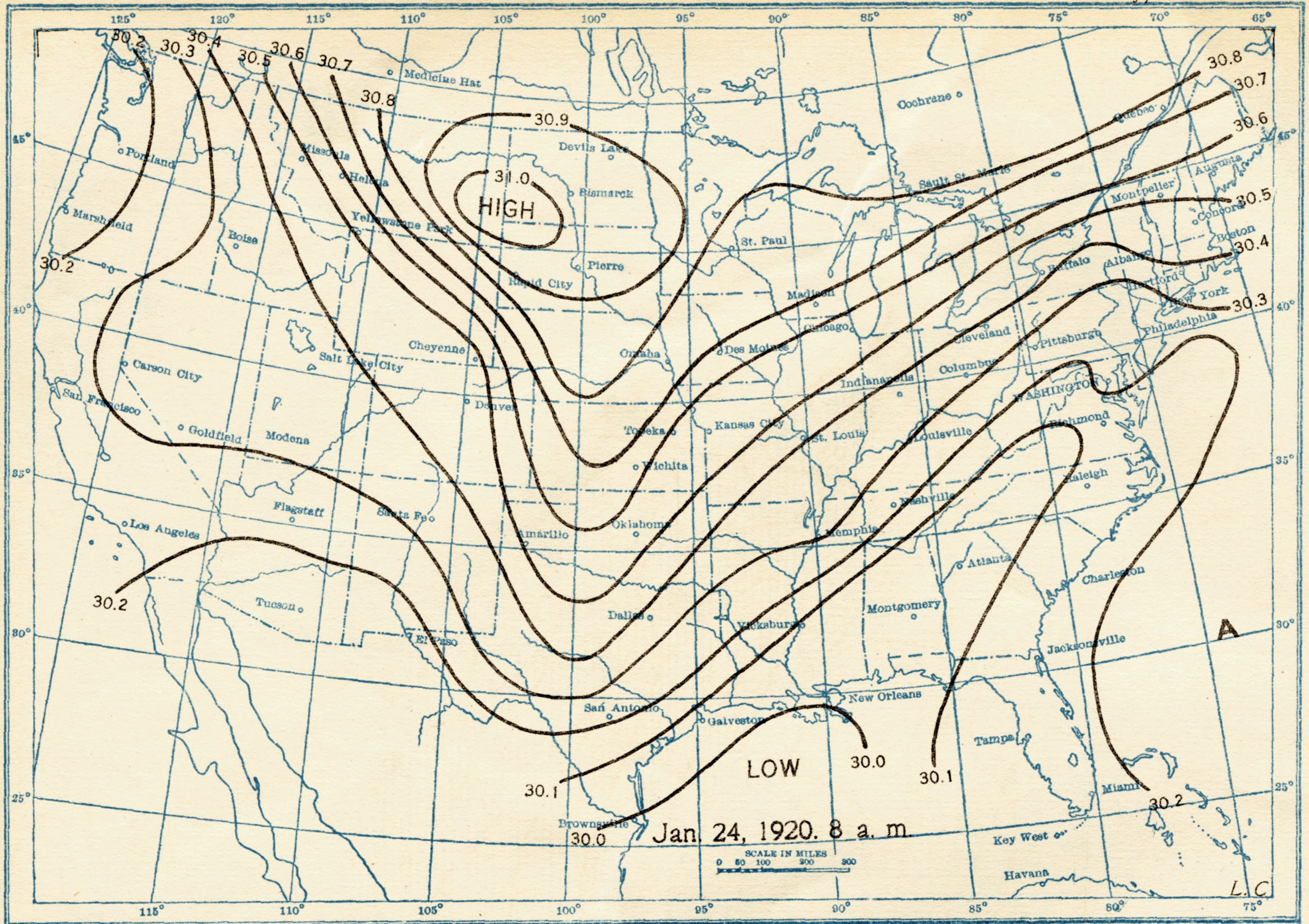
Omaha
Des Moines
Salt Lake City
Carson City
Columbus
Indianapolis
Washington
San Francisco
Denver
Topeka
Kansas City
St. Louis
Louisville
Richmond
Goldfield
Modena
Wichita
Raleigh
Nashville
Flagstaff
Santa Fe
Amarillo
Oklahoma
Memphis
Los Angeles
Atlanta
Charleston
Tucson
Dallas
Vicksburg
Montgomery
El Paso
Jacksonville
A
San Antonio
New Orleans
Galveston
Tampa
Miami
Brownsville
Jan. 23, 1920. 8 p. m.
Key West
SCALE IN MILES
Havana
L. C.


Medicine Hat
Cochrane
Quebec
Devils Lake
Bismarck
Portland
Missoula
Helena
Sault St. Marie
Montpelier
Augusta
Concord
Boston
Marshfield
Boise
Yellowstone Park
St. Paul
Pierre
Rapid City
Buffalo
Albany
Hartford
New York
Philadelphia
Madison
Chicago
Cleveland
Pittsburgh
Cheyenne
Omaha
Des Moines
Salt Lake City
Carson City
Columbus
Indianapolis
Washington
San Francisco
Denver
Topeka
Kansas City
St. Louis
Louisville
Richmond
Goldfield
Modena
Wichita
Raleigh
Nashville
Flagstaff
Santa Fe
Amarillo
Oklahoma
Memphis
Los Angeles
Atlanta
Charleston
Tucson
Dallas
Vicksburg
Montgomery
El Paso
Jacksonville
B
San Antonio
New Orleans
Galveston
Tampa
Miami
Brownsville
Jan. 23, 1920. 8 p. m.
Key West
SCALE IN MILES
Havana
L. C.


H.B.
SNOW
SLEET
RAIN
Within preceding 12 hours.
A
B
Jan. 23, 1920 8 p. m.
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
= Glaze forming.
K→ = Kite observation.
B→ = Balloon observation.
WIND BOUNDARY
CLOUDS?
CLOUD BASE
3 km.
2 km.
1 km.
Surface
A
B
C
D


30.2
30.3
30.4
30.5
30.6
30.7
30.8
30.9
31.0
HIGH
LOW
30.0
30.1
Medicine Hat
Cochrane
Quebec
Devils Lake
Bismarck
Portland
Marshfield
Missoula
Helena
Yellowstone Park
Boise
Sault St. Marie
Montpelier
Augusta
Concord
Boston
St. Paul
Pierre
Rapid City
Madison
Chicago
Buffalo
Albany
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New York
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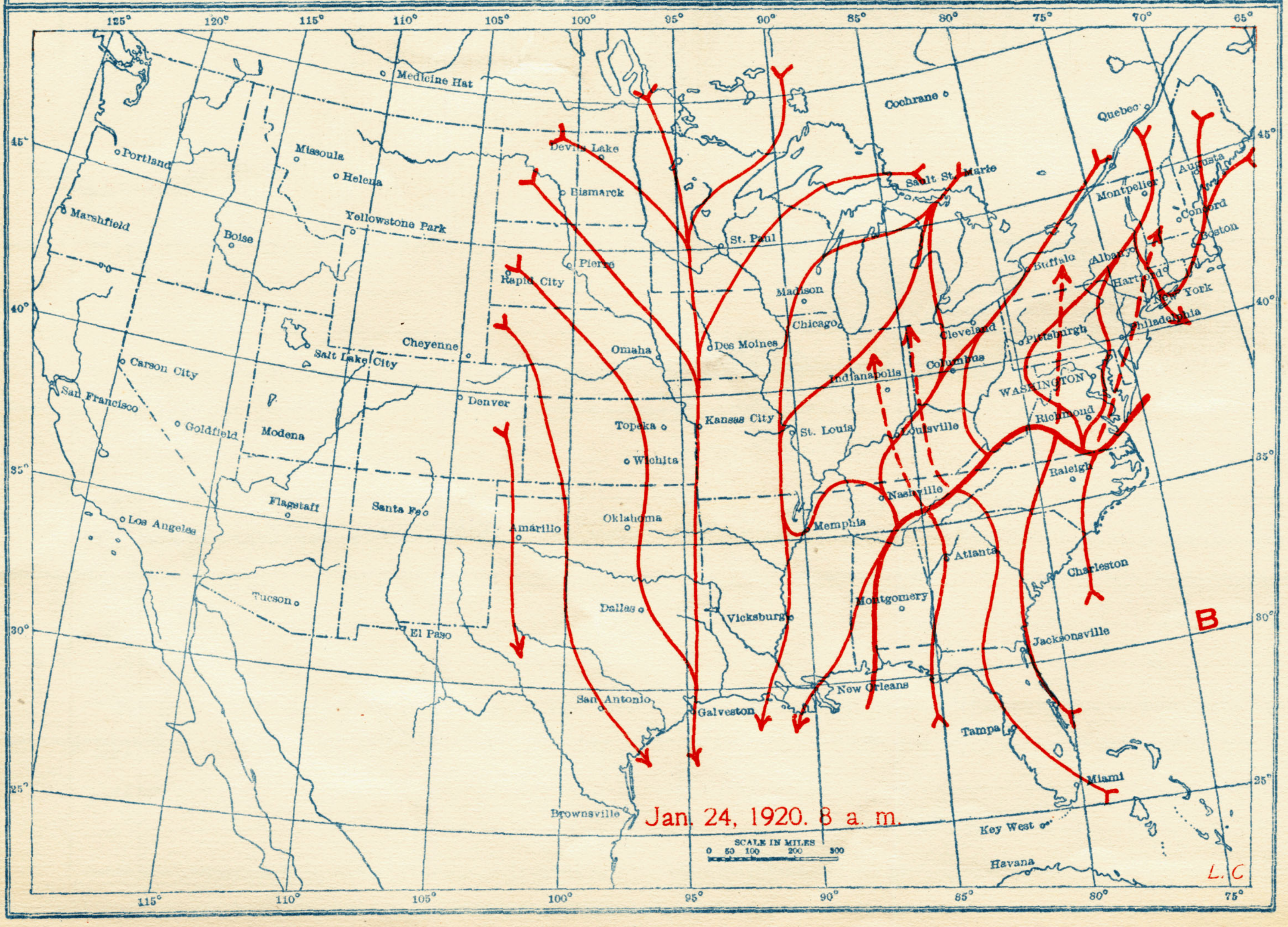
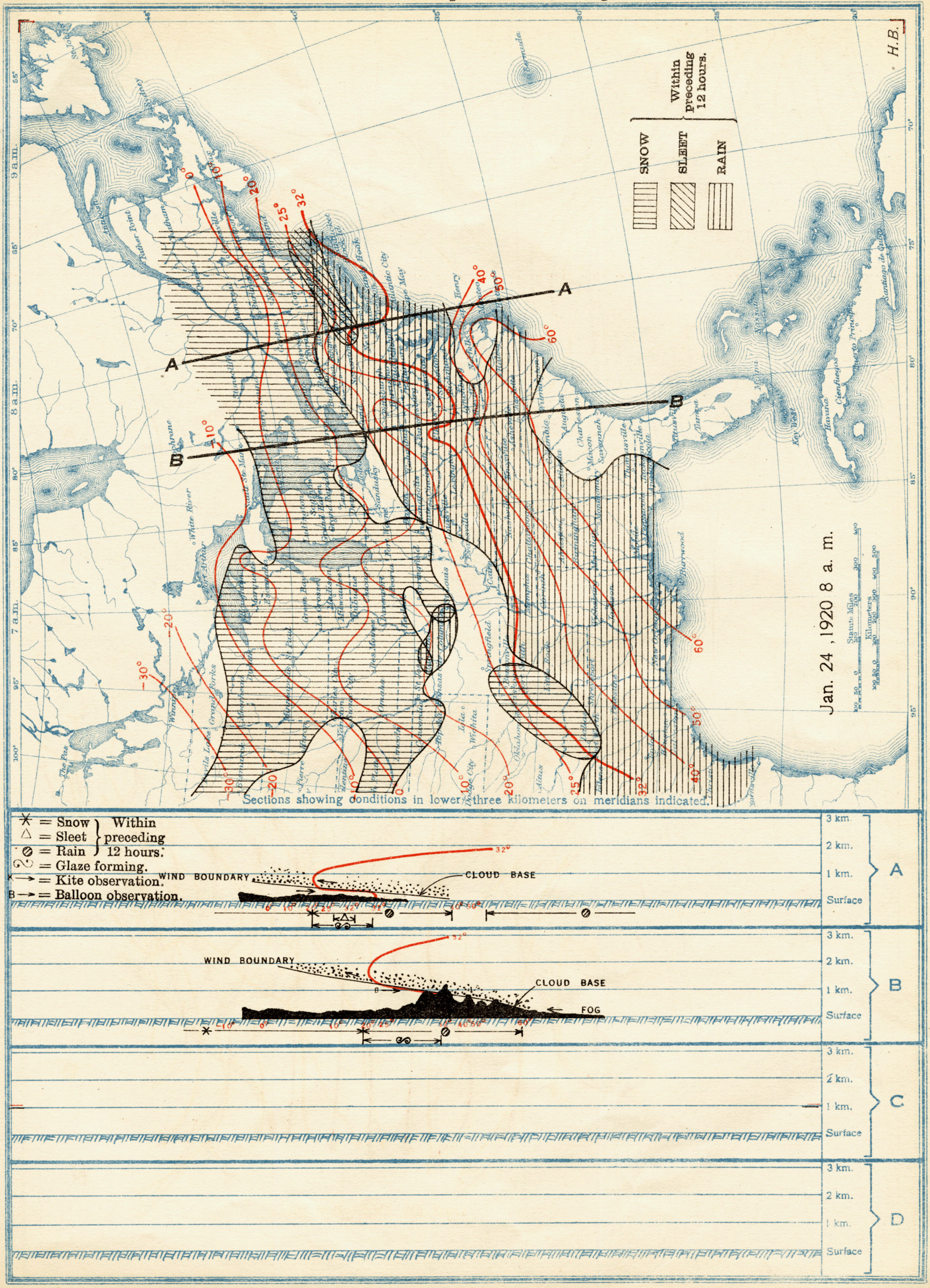
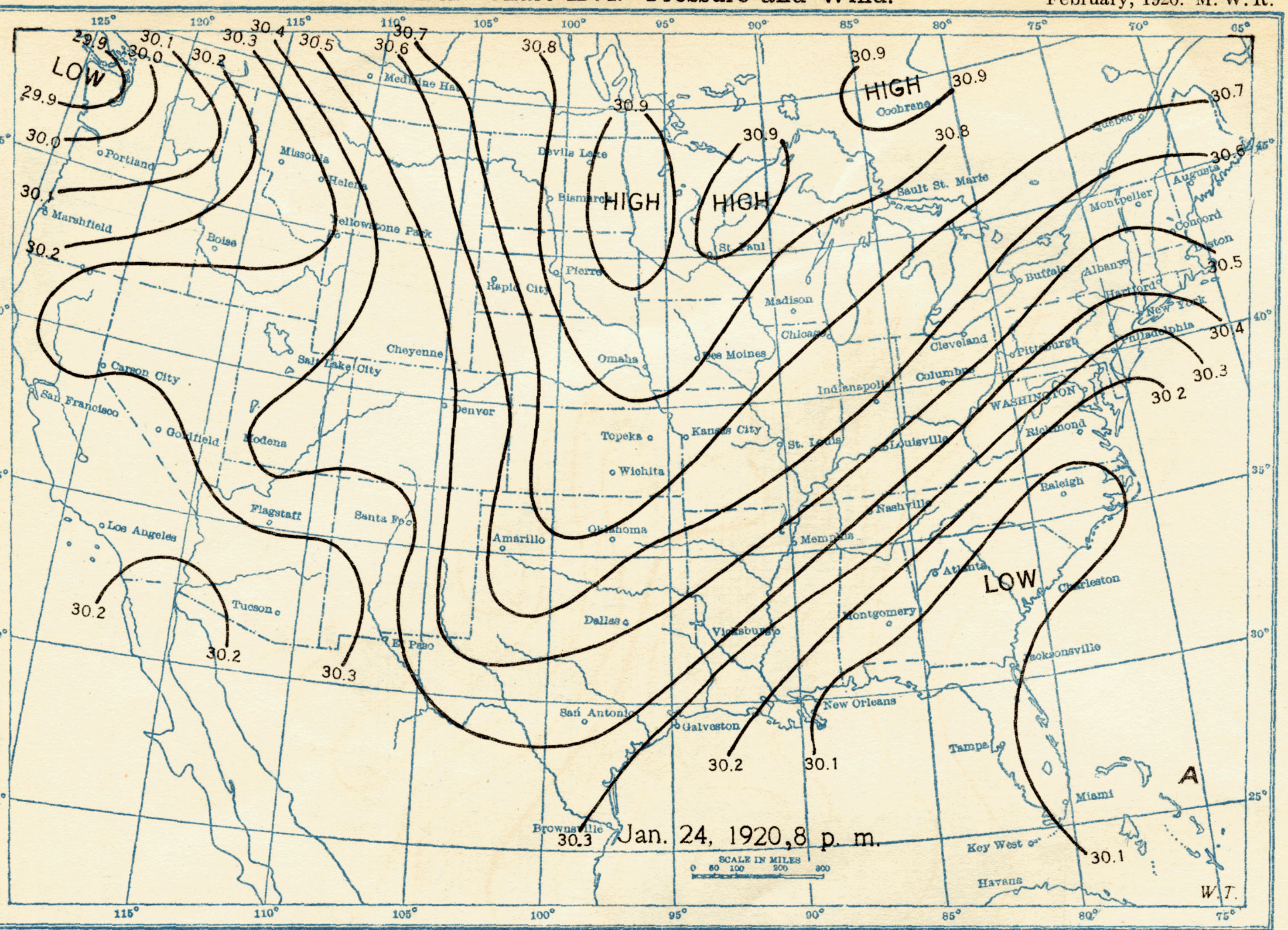
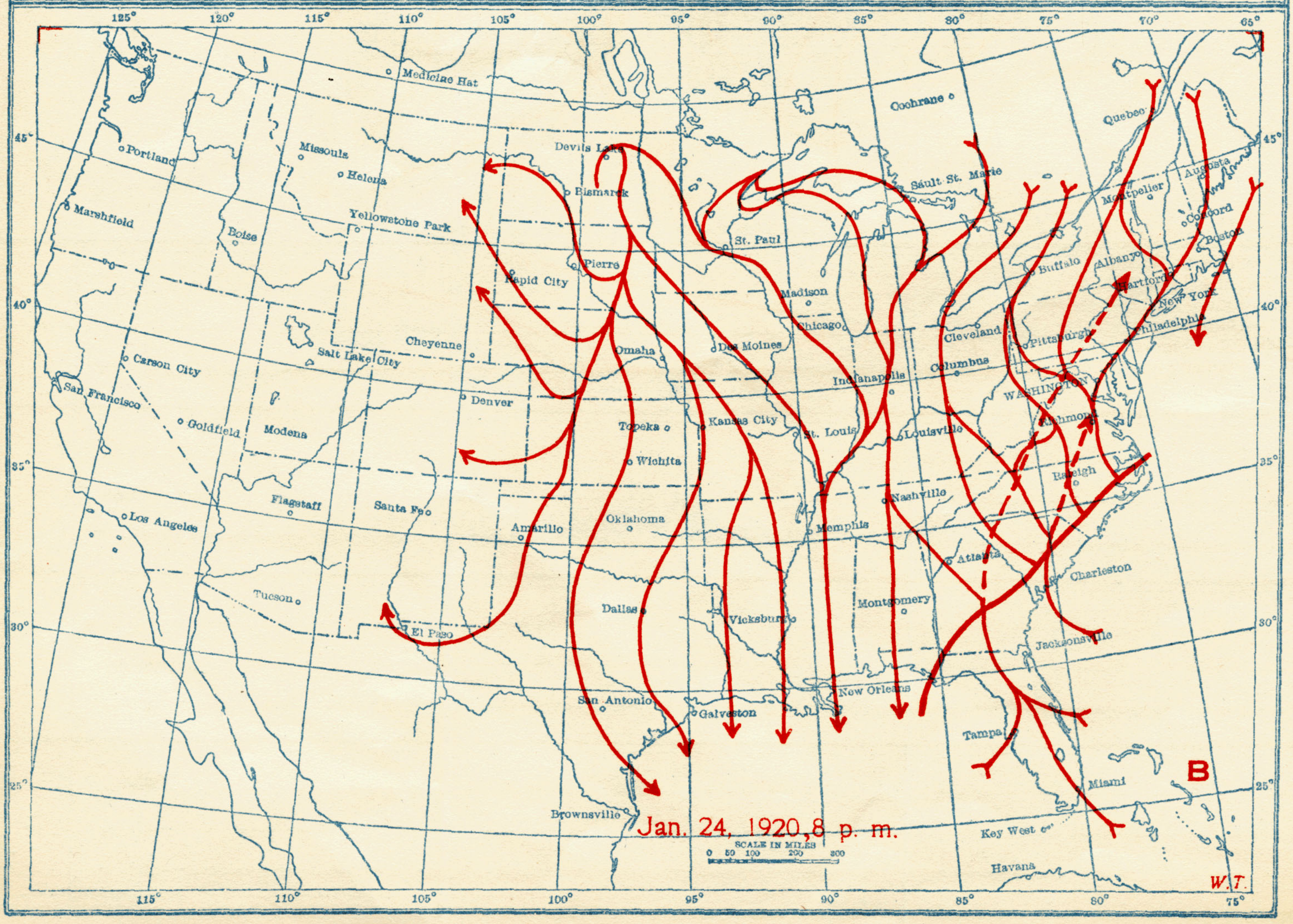
Salt Lake City
Omaha
Des Moines
Cleveland
Pittsburgh
Carson City
San Francisco
Denver
Indianapolis
Columbus
Washington
Goldfield
Modena
Topeka
Kansas City
St. Louis
Louisville
Richmond
Wichita
Nashville
Raleigh
Los Angeles
Flagstaff
Santa Fe
Amarillo
Oklahoma
Memphis
Atlanta
Charleston
Tucson
Dallas
Montgomery
El Paso
Vicksburg
Jacksonville
New Orleans
San Antonio
Galveston
Tampa
Miami
Brownsville
Key West
Havana
Jan. 24, 1920. 8 a. m.
SCALE IN MILES
A
L. C.


Medicine Hat
Cochrane
Quebec
Devils Lake
Bismarck
Portland
Marshfield
Missoula
Helena
Yellowstone Park
Boise
Sault St. Marie
Montpelier
Augusta
Concord
Boston
St. Paul
Pierre
Rapid City
Madison
Chicago
Buffalo
Albany
Hartford
New York
Philadelphia
Cheyenne
Salt Lake City
Omaha
Des Moines
Cleveland
Pittsburgh
Carson City
San Francisco
Denver
Indianapolis
Columbus
Washington
Goldfield
Modena
Topeka
Kansas City
St. Louis
Louisville
Richmond
Wichita
Nashville
Raleigh
Los Angeles
Flagstaff
Santa Fe
Amarillo
Oklahoma
Memphis
Atlanta
Charleston
Tucson
Dallas
Montgomery
El Paso
Vicksburg
Jacksonville
New Orleans
San Antonio
Galveston
Tampa
Miami
Brownsville
Key West
Havana
Jan. 24, 1920. 8 a. m.
SCALE IN MILES
B
L. C.


H.B.
SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 24, 1920 8 a. m.
Statute Miles
Kilometers
9 a.m.
8 a.m.
7 a.m.
A
B
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
= Glaze forming.
= Kite observation.
= Balloon observation.
WIND BOUNDARY
CLOUD BASE
FOG
32°
3 km.
2 km.
1 km.
Surface
A
B
C
D


LOW
HIGH
HIGH
HIGH
LOW
29.9
30.0
30.1
30.2
30.3
30.4
30.5
30.6
30.7
30.8
30.9
Medicine Hat
Portland
Missoula
Helena
Marshfield
Boise
Yellowstone Park
Devils Lake
Bismarck
Pierre
Rapid City
St. Paul
Sault St. Marie
Cochrane
Quebec
Montpelier
Augusta
Concord
Boston
Albany
Hartford
New York
Philadelphia
Buffalo
Cleveland
Pittsburgh
Columbus
Washington
Richmond
Raleigh
Charleston
Jacksonville
Tampa
Miami
Key West
Havana
Madison
Chicago
Des Moines
Omaha
Indianapolis
Louisville
St. Louis
Kansas City
Topeka
Wichita
Nashville
Memphis
Atlanta
Montgomery
Vicksburg
New Orleans
Oklahoma
Amarillo
Dallas
San Antonio
Galveston
Brownsville
El Paso
Santa Fe
Denver
Cheyenne
Salt Lake City
Modena
Flagstaff
Tucson
Los Angeles
Goldfield
Carson City
San Francisco
A
Jan. 24, 1920, 8 p. m.
SCALE IN MILES
W.T.


Medicine Hat
Portland
Missoula
Helena
Marshfield
Boise
Yellowstone Park
Devils Lake
Bismarck
Pierre
Rapid City
St. Paul
Sault St. Marie
Cochrane
Quebec
Montpelier
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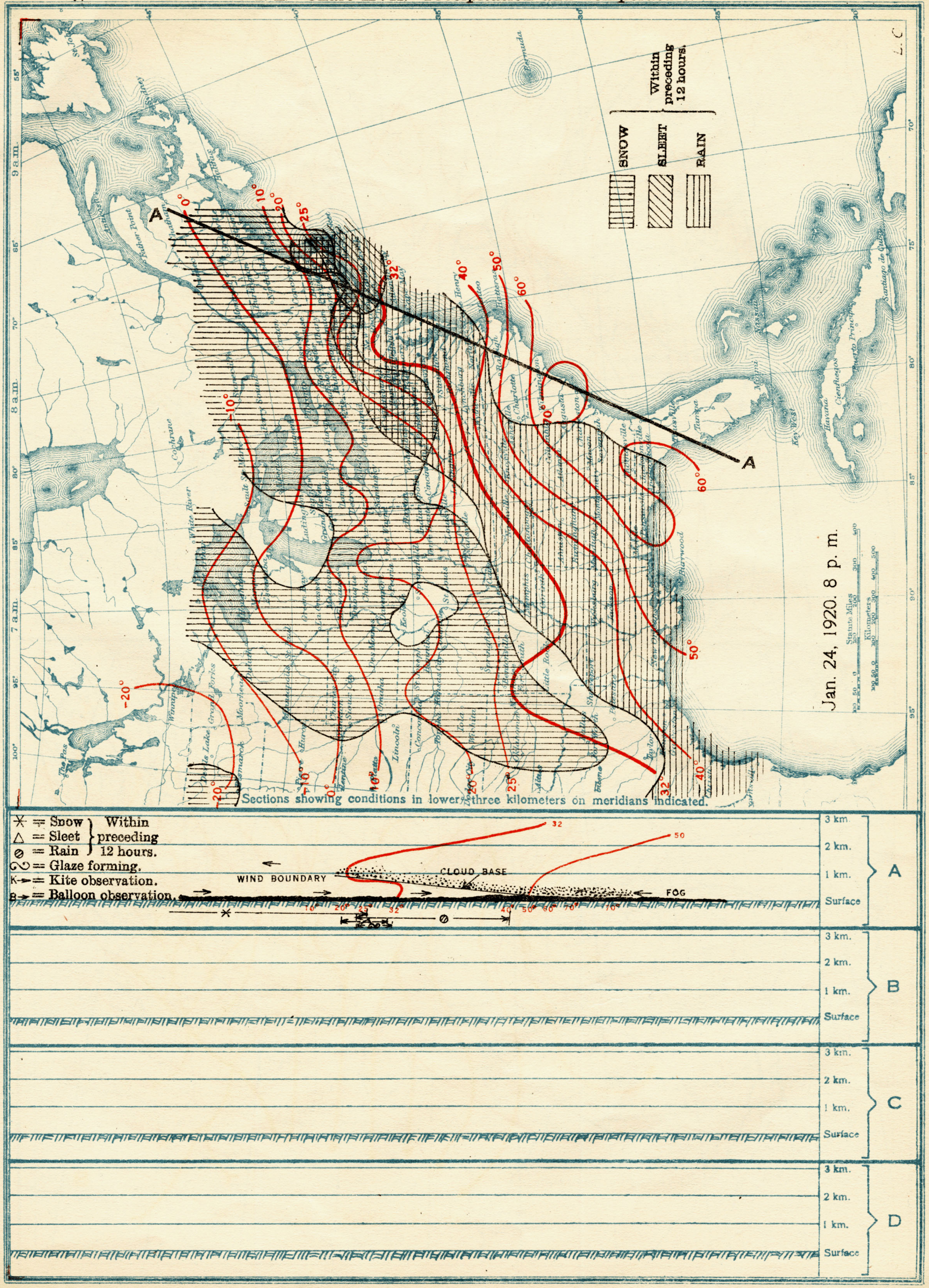
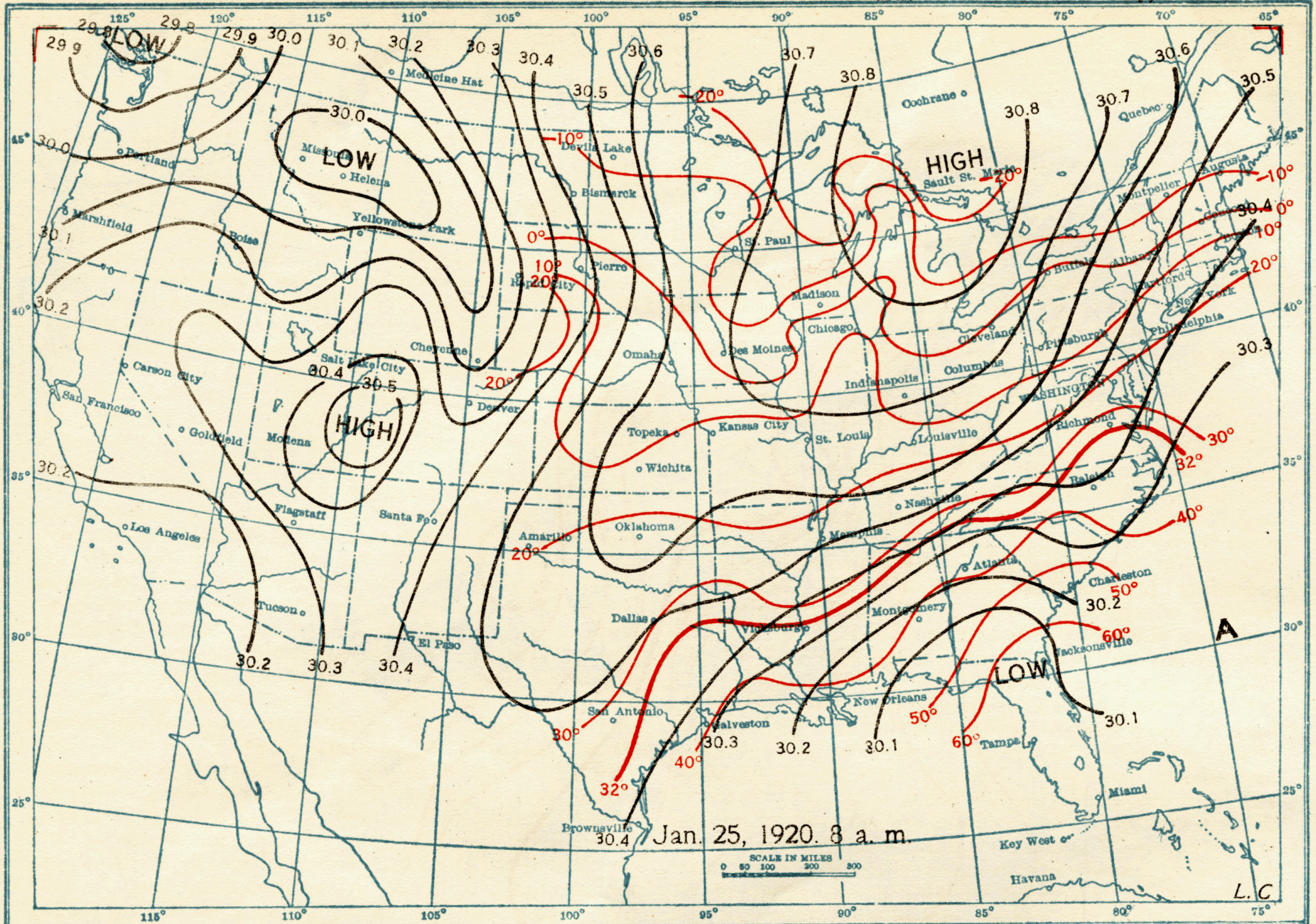
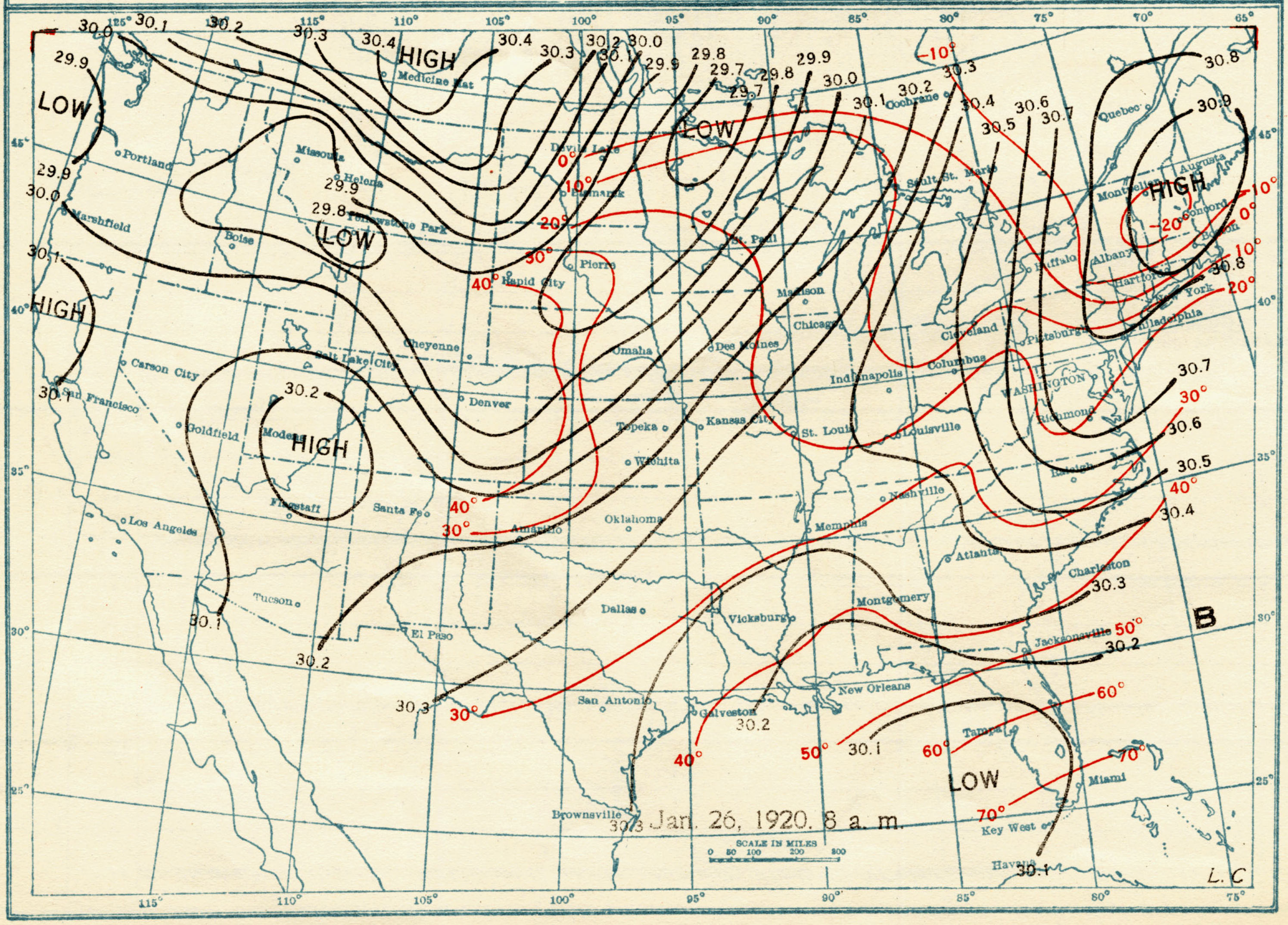
Concord
Boston
Albany
Hartford
New York
Philadelphia
Buffalo
Cleveland
Pittsburgh
Columbus
Washington
Richmond
Raleigh
Charleston
Jacksonville
Tampa
Miami
Key West
Havana
Madison
Chicago
Des Moines
Omaha
Indianapolis
Louisville
St. Louis
Kansas City
Topeka
Wichita
Nashville
Memphis
Atlanta
Montgomery
Vicksburg
New Orleans
Oklahoma
Amarillo
Dallas
San Antonio
Galveston
Brownsville
El Paso
Santa Fe
Denver
Cheyenne
Salt Lake City
Modena
Flagstaff
Tucson
Los Angeles
Goldfield
Carson City
San Francisco
B
Jan. 24, 1920, 8 p. m.
SCALE IN MILES
W.T.


SNOW
SLEET
RAIN
Within preceding 12 hours.
Jan. 24, 1920. 8 p. m.
Statute Miles
Kilometers
A
A
Sections showing conditions in lower three kilometers on meridians indicated.
✳ = Snow
△ = Sleet
⊘ = Rain
Within preceding 12 hours.
= Glaze forming.
K→ = Kite observation.
B→ = Balloon observation.
WIND BOUNDARY
CLOUD BASE
FOG
3 km.
2 km.
1 km.
Surface
A
B
C
D


A
Jan. 25, 1920. 8 a. m.
HIGH
LOW
LOW
HIGH
LOW
SCALE IN MILES
L. C


B
Jan. 26, 1920. 8 a. m.
LOW
HIGH
LOW
LOW
HIGH
HIGH
HIGH
LOW
SCALE IN MILES
L. C

stood: it does not show the actual paths of particles of air, but, on the contrary, merely the directions with which the winds were blowing *at the time of observation*. This method has been devised by Bjerknes[4] and has been used by him in his studies in forecasting in Norway and other parts of the world. Our maps also show, wherever possible, the probable path of the wind of southerly component after it has left the ground at the wind-shift line. In these maps the surface winds are shown in red and the probable course of the southerly wind aloft by dotted lines.

Opposite these maps, for a given time, is the map showing the distribution of precipitation of various kinds during the preceding 12 hours. This shows, in overlapping areas, the character of the precipitation. By placing the isotherms on this map we are able to show the region which probably includes the areas over which glaze formed, namely, all that area north of the freezing line (32° F. isotherm) over which rain fell during the preceding 12 hours. In addition to the isotherm of freezing, which, owing to its importance is more prominent than the others, the isotherms of 25°, 20°, 10° (F.) etc., are marked north of the freezing line, and 40°, 50° (F.), etc., are marked south of the freezing line.

On the lower part of the precipitation and temperature map, we have prepared sections of the lower 3 kilometers of the atmosphere along selected meridians. The meridian selected is noted by a heavy black line on the map, and its corresponding section below is found by means of the index letter. These sections are the result of putting together those fragmentary data which, owing to the regrettable scarcity of aerological stations in the United States, consist of isolated temperature measurements at various levels in the free air, and of wind directions and speeds, amplified with speculations which are based upon previous observations. Thus, while these sections can not lay claim to being actual representations of the conditions aloft, they may be regarded with considerable confidence.

These maps have been prepared for every 12 hours throughout the period under investigation, beginning with January 21, 8 a. m. The last two maps (Chart XVIII) show the pressure and temperature conditions on January 25 and 26, to connect the weather of this period with that of the 27th to 31st discussed in the following article in this REVIEW.

GENERAL SURVEY OF THE PERIOD.

Pressure.—The period opens (Chart I, pressure and wind-shift are noted on same map with other data for January 20, 8 p. m.) with the territory under consideration flanked by high pressure in the northwest, northeast, and southeast, with moderate depressions in the Lake region and in the Southwest. The subsequent changes of pressure served to produce a general broad area, or wall, of high pressure along the northern part of the United States, while there was a general decrease toward the Gulf which was manifested in the Gulf States by a fairly persistent protuberance of lower pressure which extended from the Gulf to western North Carolina and Virginia (Chart IVa). The general area of high pressure off the southeast coast was also quite persistent. On the morning of January 23 a small depression was centered over northeastern Arkansas (Chart Xa) and by evening of the same day was elliptical in form with its major axis roughly parallel to the Appalachian Mountains. With the strengthening of the high pressure in the north and the appearance of a center in northern Minnesota on January 24 (Chart XVIa), the isobars assumed a southwest-northeast trend with the protuberance of low pressure, previously mentioned, lying along the south Atlantic coast. This was followed, coincidently with the general disappearance of sleet conditions, by an easterly motion of the HIGH to the Lake region, and the southeastern LOW to Florida (Chart XVIII), on the morning of January 25.

What is the significance of this pressure distribution, with respect to the conditions favorable for sleet and glaze? We mentioned above that one of the major premises of a sleet forecast is the presence in the southeast of a HIGH, the temperatures within which are not so low as usual, just off the coast of southeastern United States. Such a condition persisted until the last few hours of the period. Moreover, the belt of high pressure, evidently centered far north in Canada, gave an abundant supply of cold air, sweeping down from the deep snow-fields of the north far into the United States toward the general area of low pressure along the southern coast. The return flow of warm moist air, riding over the wedge-like encroaching north wind, was cooled and forced to precipitate rain, sleet, or snow over most of the eastern United States throughout the period.

Wind.—Now, let us look to the charts of instantaneous stream lines of surface wind. Chart I shows a strongly marked wind-shift line (heavy dotted red line) extending from Texas northeasterly toward the center of low pressure over Lake Erie. South of this line all the winds, with certain exceptions in the mountain district where topography prevents the surface air from flowing readily with the general wind not far aloft, have a south component. (Indicated on Chart I by heavy red arrows.) All winds north of this line have a north component. Chart IIb shows the same wind-shift line extending from east Texas to New England with a slight break in North Carolina, owing to the slight depression centered in that region. Throughout the period, it is possible to see this line, sometimes rather indefinitely located, as in Chart VIb, for instance, but recovering its identity a few hours later as in Chart Xb. As the end of the period approached, the sweep of the northerly wind became greater until finally it covered the Gulf and South Atlantic coasts. (Charts XIVb, XVIb, XVIIIa.)

Temperature and precipitation.—The picture of the current weather is completed, as far as our interests are concerned, by the odd-numbered charts, which show the temperature at the surface and the areas over which various kinds of precipitation have occurred in the preceding 12 hours. Briefly, attention is called to the general aspects of these charts. The period begins with general precipitation west of the 95th meridian. The area of glaze covers Illinois and the northern portions of Indiana and Ohio, and again in the east, a considerable portion of the Middle Atlantic States. Sleet also fell over a large area from Lake Michigan eastward to the Atlantic and as far south as Philadelphia. The following 12-hour period shows the major portion of the sleet area to lie in Missouri and southern Illinois and Indiana (Chart III), with another, smaller area in Pennsylvania and New York. Attention, however, should be called to the fact that the maps representing precipitation during the night hours seem to show a tendency toward spottedness of sleet. It is believed that this is attributable to the lack of close and careful observation during the night hours. Even during

[4] Bjerknes, V. F.: Synoptical representation of atmospheric motions. Quar. Jour. Royal Meteorological Soc. 36: 267-286; also, Weather forecasting, and, On the structure of moving cyclones. MONTHLY WEATHER REVIEW, February, 1919, pp. 90-99.

the day it is an easy matter to fail to note sleet when it is falling in small quantity with rain or snow, and the night would only increase the difficulty. This, combined with the less vigilant night observations, might account for the spottedness of sleet areas. The general trend of the isotherm of freezing throughout the period is from southwest to northeast and the rain areas conform in general to the same direction, the rain belt extending roughly equal distances on either side of the isotherm. As the period draws to a close the areas of sleet and glaze grown smaller and, while large areas of snow and rain are still prevalent, the sleet and glaze producing conditions are disappearing.

Another outstanding feature of the temperature distribution is the distinct northward hook in the mountain region, the line of freezing often proceeding far north of its general trend because of the inversion of temperature which results from the overrunning warm wind from the south. The lower stations, therefore, are in the northerly wind, but those of greater elevation project up into the warmer region and swing the isotherms far from their normal course, i. e., the course they would probably pursue if the mountain region were absent. This inversion is nicely shown on Chart VII in which Elkins, W. Va., shows a temperature several degrees higher than the territory in its immediate neighborhood. Toward the end of the period, with deep northerly winds, the opposite is the case (Chart XV), for Elkins has a temperature considerably lower than that of the surrounding country.

THE MERIDIONAL SECTIONS.

Example.—In order that the significance of the small meridional cross-section maps may be thoroughly understood, the method employed in drawing them will be followed through for one case, which is fairly complete in details. Not all of these sections are of equal weight owing to the lack of upper-air data in many cases, but the reasoning employed in their construction is something as follows: Let us take Section A on Chart III, which represents the conditions along the 83d meridian at 8 a. m., 75th meridian time, January 21. The general nature of the topography is indicated in solid black. The surface temperatures, that is, the points where the various isotherms of the map above intersect the black line AA, are indicated along the "surface" line. From Chart IIb, on the opposite page, we find that the wind-shift line crossed this meridian in northern Georgia, which is to say *that all winds south of the line* had a southerly component and all winds north of the line had a northerly component. Moreover, that same morning at Leesburg, Ga., a kite flight was made. The conditions there were fog at the surface and winds of southerly component as high as 3 kilometers. The surface temperature was 57° F.; and at 1, 2, and 3 kilometers were 52°, 51°, and 41°, respectively. The record showed a layer of stratus cloud having its base at about 1,200 meters, and its top as indicated by the hygrometer and thermograph, at about 1,500 meters. Within the cloud, the temperature fell to 50°, which is approximately according to the retarded adiabatic rate. Immediately at the top there was a sudden rise to the 54° observed at 1,500 meters. Above that level the temperature fell at the greater rate of about 1° F. per 100 meters.[5]

At Lansing, Mich., where a pilot balloon run was obtained, winds of northerly component up to 2 kilometers showed clearly that the wind-shift line which was on the ground in northern Georgia must lie somewhere aloft in the intermediate distance. Royal Center, Ind., which is in the vicinity of the meridian in question, showed a northerly component at 1 kilometer and clouds at about 1,500 meters. What clue can that give to the location of the wind-shift line? It is likely that at the boundary between the winds of north and south component, there will be clouds formed by mixture, that is, the mixing of the cold air from the north with the warm, moist air from the south, will produce a region of intermediate temperature, below the dew point for air of that moisture content, with the result that cloud will form. Thus, if we find cloud at 1,500 meters above Royal Center, we are probably not far wrong in saying that that is the boundary between the winds of north and south component; hence, we will be justified in joining the wind shift at the surface with this point in the free air and call that line our "wind boundary," and since fog is not found north of the wind-shift line we may assume that the wind boundary forms the cloud level. The upper level of stratus which we found at Leesburg, Ga., will intersect this wind boundary and will extend as far north as surface stations report cloudiness, which was approximately in central Ohio. From Leesburg north to the point where the wind boundary is encountered, the base of the stratus cloud will probably be lowered, because of the horizontal temperature gradient at the surface which will tend to bring the dew-point level nearer the surface; at the same time, the cloud layer will thicken because the air is rising, in other words, the top is raised by forced ascent as the warm air rides up over the wedge of cold air from the north.

Now, let us consider the vertical distribution of temperature, which may be well surmised, knowing the surface horizontal distribution and the upper-air conditions with respect to height and thickness of clouds, and wind direction. Beginning with the 32° isotherm we find that it lies well within the north wind, thus the likelihood of a temperature inversion is small and if it did exist, it would not be very strong; hence, we can assume the temperature gradient up to the cloud base is the normal for winter. But as soon as the south wind is encountered the temperature at that point is certain to be considerably higher, since the temperature of the south wind when it left the ground was about 52° F., and, judging from the slight cooling due to ascent, and due to latitude it is very certain that the isotherm of freezing must swing decidedly to the north. How far north will it go? We must now look to the areas of different kinds of precipitation, shown on the map above. We find that rain fell from the vicinity of the wind-shift line at the surface in Georgia to central Ohio. About half the rain area, along the 83d meridian, lay north of the surface freezing line. But we know that if rain falls upon earth below the freezing temperature, there must be a higher temperature aloft in which rain may form or in which the snow will melt as it falls through. Such a layer must, obviously, be above freezing. So we carry our freezing line from the point where it enters the cloud closely along the wind boundary to the northern limit of the glaze belt, or, more strictly, the northern limit of rainfall of the preceding 12 hours.

This brings to light the fact that the sections are not synchronous throughout, but that the surface location of the 32° isotherm is current, whereas its northern limit aloft is really its northern extreme during the preceding

[5] Unfortunately, it was necessary, owing to the manner in which data are presented by Weather Bureau stations, to employ temperatures and pressures in Fahrenheit degrees and inches, respectively, and altitude in meters. But since the mixing of the systems of units, in this case, does not result in confusion, the author has refrained from the conversion of large numbers of observations to metric units.

12 hours. Sleet is formed by partially (or totally) melted snow falling into a cold layer and refreezing, or by the freezing of raindrops in the air; but since no sleet fell on on this meridian we should be led to think that the thickness of the layer whose temperature was above freezing was large, since no snow, which may have fallen from higher levels, was able to get through only partially melted. Curving the freezing line back at this point, we start it in a southerly direction again at the retarded adiabatic rate. Taking the 40° isotherm, in a similar manner, we raise it at a normal rate to the cloud level, then sharply northward, as it encounters the southerly wind, but not so far as the 32° line. As it rises through the cloud it follows the retarded adiabatic rate until it reaches the cloud top, where there is a sharp inversion (mentioned before in connection with the observed 51° at Leesburg), and then it proceeds at a more rapid rate, say 1° F. per 100 meters.

We have then, the picture of the processes at work in producing glaze formation, the underrunning north wind, the overriding south wind, the immense value of even a few kite and pilot balloon observations, in piecing together a cross section of the phenomena of the upper air. Not all the sections will be so complete. Some are devoid utterly of assistance from the upper-air observations, because there were no stations near enough whose observations could be considered as applicable to the meridian in question. This detailed explanation of the method of constructing a cross-section shows what considerations were given to each of the others, to a greater or less degree.

Some interesting features.—As one follows through the sections there are a number of points which are brought to notice in a very striking manner. Among the first of these is Section C, Chart III, which shows the effect of gentle southerly winds, ascending over a wedge of northerly wind which is apparently descending. This fact is ascertained from the kite observations at Ellendale, N. Dak., in which we find a wind of northerly component at 2 and 3 kilometers, but of southerly component below 1 kilometer. It is obvious from the stream-line map (Chart IIb) that the southerly surface wind at Ellendale can not be related to the southerly wind of the more southerly latitudes. Hence, we must think of the formation as a series of layers of different direction sliding over one another. The wind-shift line or wind boundary probably does not extend far north as we have assumed others to do, but is prevented by the superior strength of the northerly wind. A second wind boundary, unrelated to our investigation, would be that between the southerly and northerly winds above Ellendale.

A similar phenomenon appears in Section C, Chart V, in which the northerly component is introduced by a northeast wind which, at its maximum, is perhaps not over a kilometer and a half in depth. This forces itself like a wedge from the side under the southerly wind, lifting it in a broad hump, but allowing the southerly wind to meet the surface again in the north. This is shown by kite flights at Ellendale, which seem to indicate that an adiabatic temperature gradient prevails above that region. In the south, however, where the isotherm of freezing is to be found, the sky is partly cloudy, marking the northern edge of the cloud level, but the clouds are moving from the south, while just below that level, a pilot balloon observation at Broken Arrow, Okla., discloses a wind of northerly component. Another feature of interest is that the precipitation of the preceding 12 hours occurred all on the windward slope of the wind hump, just as it would on a topographic hump, where a passing moist southerly wind would have been cooled by expansion rising on the southern slope, making precipitation, but warmed by compression flowing down the northern slope, tending to evaporate the clouds.

A warning should be made here. The section we are discussing shows the northern cloud limit considerably south of the northern limit of rain as shown in the symbols beneath, and it is desired to mention again that the precipitation refers to the preceding 12 hours, while the cloudiness, temperature, etc., are current. Confusion in trying to reconcile precipitation with a clear sky will be avoided if this is borne in mind.

Section A, Chart V, shows the northern limit of rain and sleet coinciding with the maximum altitude of the land. This is shown also in Section A, Chart VI; Section A, Chart IX and Section A, Chart XI. There are probably two reasons for this phenomenon, operative in combination. First, as the southerly wind approaches the mountainous regions it is deflected upward by the land itself, causing precipitation from clouds formed by forced ascent: second, it is possible that rain is falling from the cloud all along, but that the surface temperatures in the more southerly region are sufficiently high to evaporate the falling rain before it reaches the surface. But as greater elevations are attained in the topography, and as the surface temperature is lower in more northerly latitudes, rain reaches the surface, chiefly because the earth goes up to meet the rain.

One will notice on Chart XIII, Section B, that there was a narrow region where sleet was reported in combination with snow, and south of the region of sleet and snow there is an area where snow alone fell. It seems natural in the ideal section of the atmosphere that the sequence of precipitation from the south along a given meridian should be rain, rain and sleet, sleet, sleet and snow, snow; and, in general, such a sequence is found. But here we have an area of sleet falling in the midst of a snowstorm. The sky is overcast with low clouds from which snow is falling. Surely there can be no temperature of freezing or above below those clouds and in a northerly wind. We must draw upon our imagination to find the source of the sleet. We know that it may start as snow and fall through a layer of air whose temperature is above freezing. Therefore we may suppose that there is a cloud layer precipitating snow at some elevation above the tongue of southerly air, and that either this cloud area is small because the area of sleet on the ground is small, or that only a small portion of it is under-run by warm air. Hence, we may mark a cloud layer at roughly 2 kilometers. But the presence of this sleet area is made more interesting by an observation made earlier in the day at Leesburg, Ga.

Upon January 23 (Chart XI, Sec. B), after a morning fog had cleared, a layer of [alto]stratus clouds at about 2 kilometers was seen moving rapidly northward. Low clouds prevented us from knowing how far north this layer extended. The wind was of considerable velocity from the south, and if we may assume that the layer extended for a considerable distance north of the place of observation, it is quite conceivable that the clouds which produced the sleet in Section B, Chart XIII, are the same as those headed rapidly northward from Leesburg. This is not a far-fetched conclusion, but is an interesting piece of aerological detective work.

A fourth point worthy of attention is seen in Section B, Chart VII. Here there is no wind-shift line; the surface wind throughout the length of the meridian is northerly. There are no kite stations within the immediate vicinity of this meridian, nevertheless, those at Drexel, Nebr., show a wind of southerly component and of temperatures consistent with those at the surface and with the area over which sleet fell. It is therefore probable that over this whole region there was only a shallow north wind and a south wind above it of considerable depth.

Finally, mention should be made of the apparent discontinuity between the areas of rainfall and snowfall. Except for those periods when precipitation was general throughout the eastern half of the United States, as in Chart XIII, there appears a well-defined clear space on the maps in which no precipitation occurred lying between the rain area and the snow area. This shows how the snowfall was probably attributable to a cause quite distinct from that which was producing the rain and sleet farther south. For example, take Charts VII, IX, and XI, in which there is shown the advance from the northwest (first appearing in North Dakota on our charts) of an area of snowfall, first, only a small area being visible, then widening and advancing, and, finally, joining itself to the general precipitation area. The cause of this is probably as follows: A glance at the pressure map VIa shows that a high-pressure area was appearing in this region, and that snow was falling where the pressure gradient was steepest, the precipitation apparently being the result of forced ascent of the air as it flowed into this belt from the rear at a higher velocity than it flowed out in front.

THE STORM OF FEBRUARY 3–6, 1920.

While the precipitation of sleet and the formation of glaze during the period of February 3 to 6 was more local in character and somewhat shorter in duration than the one we have just discussed, it may be safely said that it stands out in the minds of those who experienced it as one of the most severe storms in years. It occurred chiefly east of the Appalachian Mountains, hence, because of the relatively small area covered we have not considered it in the detailed manner of the previous storm, and no charts have been drawn for it. The conditions in New England have had a parallel only in three or four instances. Trains were stalled for days, roofs collapsed from the weight of snow and ice, and in New York City the removal of the snow and ice afforded the most perplexing problem of its kind in the city's history.[6]

The great mass of cold air over the snow-covered north, with its attending area of extremely high pressure, which lay over the North Atlantic States, afforded a strong barrier to the cyclone which, having appeared in the southeastern States, could move but slowly northward, and, therefore, increased markedly in intensity. The circulation about this strong cyclone, in combination with the HIGH in the north, served to send winds of gale force, sweeping from the northeast down the coast for several days. Above this wedge of biting wind there flowed a layer of moisture-laden air from the balmy expanses of the Gulf Stream, and in consequence there was heavy precipitation of snow (several feet) in the interior of New England, New York, and Pennsylvania, with snow, sleet, and glaze-forming rain along the coasts, while farther south there was an unusual quantity and duration of sleet and rain.

On February 3 the cyclone was centered near Savannah. The wind-shift line lay across northern Florida, thus allowing extremely warm air from Florida and the Gulf to ride up over the cold air fed by the strong wall of high pressure in the Lake Region and New England.

[6] See note on "Demoralization of traffic in New York City by snow and sleet," this REVIEW, p. 80.

On February 4, the center of the cyclone had moved out to sea from Savannah, leaving the wind-shift line slightly farther north than on the previous day, but still well marked in southern Georgia and northern Florida.

The cyclone apparently changed its course on February 5 and began to move roughly parallel to the coast in a northeasterly direction. The wind-shift line was no longer in evidence, and the horizontal surface temperature gradient was very slight, although the temperatures were rather low. Precipitation during these days was general along the coast, with heavy snows in the north, which were mixed with rain and sleet. Farther south the sleet and glaze were predominant, the sleet falling in such quantity at Washington, for instance, as to afford a cover several inches deep much like dry sand. Rain, of course, fell in the South Atlantic States. The conditions producing this storm were obviously of the same general nature as those of the previous one, except more intense and more localized. So much warm air blew inland during this storm, that after the storm passed off, the northwest wind was relatively mild in temperature.

PRECEPTS FOR FORECASTING SLEET AND GLAZE.

It was stated in the beginning that the motive for preparing this paper was the desire to find some means to improve the forecasting of sleet and glaze; at the same time it was observed that no one can well anticipate the discovery of a panacea for all the difficulties of this type of forecasting from the study of a single storm. There are, however, certain features of this storm which appear as characteristic, i. e., they seem to persist as long as the sleet and glaze persisted, and, therefore, are probably related. One of these features is the parallelism between the 32° isotherm, the wind-shift line, and the northern limit of rain and sleet precipitation.

While the extreme value of forecasting the location 12 or 24 hours later of the 32° isotherm has been pointed out in a previous reference to the statement of Dr. Frankenfield as to the conditions which produce sleet and "ice storms," it appears that it is also of extreme importance to forecast, and pay quite as great heed, to the location of the wind-shift line. For the two are inseparably related in the production of this troublesome type of precipitation.

The forecaster's desire is to forecast the area over which glaze will form, and the area over which sleet will fall. Heretofore, the centers of these regions have been forecast with fair accuracy, but often the forecasting of the limits has been difficult, if not impossible. It behooves us, then, before this paper can be completed, to investigate the question of whether or not there is any relation between the distance from the 32° isotherm to the wind-shift line, and the values in question, namely, the width of the glaze belt, the width of the sleet belt, and the distance of the center of the sleet belt north of the 32° isotherm. Consequently, these distances have been measured throughout the period along various meridians, and ratios have been formed which may serve as factors in predicting the desired values. The measures were made on 34 meridians during the storm, with no attempt to select specific conditions. In spite of the fact that the expected large divergences from the average do occur, it is surprising, nevertheless, that there is as good agreement as is found. The values which have been determined are presented with the full recognition that their determination has been purely empirical, and with the warning that they should be considered in the same cautious manner in which they are given, since they have been determined from this single storm, and may be found, when compared with other storms, to show a wide divergence.

We do not ignore the physical basis upon which such relations, as we seem to find by purely empirical measurement, may rest. The distance between the 32° isotherm and the wind-shift line is taken as the basis, and the forecasting of the location of each of these is dependent upon the pressure distribution. But the 32° isotherm is usually found in this type of storm to lie north of the wind-shift line; that is, within the area over which wind of northerly component is flowing, and warming as it reaches the southerly latitudes. The wind-shift line marks the place where the southerly wind leaves the surface and moves northward aloft. Kites and pilot balloons will show how far north this wind has progressed, providing there are enough such observations. The amount of precipitation will depend upon the moisture content of the southerly air. The ultimate extent of the southerly wind aloft will depend upon its speed, and, similarly, the ultimate extent of the northerly wind at the surface will depend upon its speed and the nature of the surface over which it is flowing. These are general considerations which the forecaster is accustomed to make, and which he can make with increasingly great certainty as he is armed with more and more data and observations from kites, pilot balloons, and clouds.

Bearing these things in mind, the empirical values referred to above are now presented, with a rough measure of the certainty or accuracy of the occurrence of the phenomenon:

$$(1)\quad \frac{\text{Width of the glaze belt.}}{\text{Distance between 32° isotherm and wind-shift line.}} = 1.0$$

$$(2)\quad \frac{\text{Width of the sleet belt.}}{\text{Distance between 32° isotherm and wind-shift line.}} = 0.7$$

$$(3)\quad \frac{\text{Distance between 32° isotherm and center of sleet.}}{\text{Distance between 32° isotherm and wind-shift line.}} = 0.8$$

The natural question is, With what accuracy do we know these values? It is obvious that in a proposition of this nature, with only 34 determinations, it is unwise to attempt to apply any statistical formulae for the expression of the probable accuracy. But of the measurements made from the maps, we may make the following statement:

For (1) with 34 cases:
- 11 agreed within 20 per cent of the mean.
- 22 agreed within 40 per cent of the mean.
- 29 agreed within 60 per cent of the mean.

For (2) with 28 cases:
- 8 agreed within 20 per cent of the mean.
- 15 agreed within 40 per cent of the mean.
- 25 agreed within 60 per cent of the mean.

For (3) with 28 cases:
- 7 agreed within 20 per cent of the mean.
- 12 agreed within 40 per cent of the mean.
- 18 agreed within 60 per cent of the mean.

One can judge that the accuracy is only sufficient to warrant interest, and possibly to stimulate investigation into other storms of this type to discover if some such empirical rule can be laid down; for if it can, it certainly will be of value in forecasting.

Let us consider the relation (if any exists) between the distance between the wind-shift line and the 32° isotherm, and (1) the width of the glaze belt 4° of longitude east 12 hours later, and (2) the width of the glaze belt 8° of longitude east 24 hours later. Since the pressure formations, and hence the weather in general, move eastward at a rate which is about 8° per 24 hours, such a relation would be of value, for, knowing the current distance between the wind shift line and the 32° isotherm, it might be possible to predict the area over which glaze will form 4° and 8° farther east 12 and 24 hours later, respectively.

Such measurements were made from the maps with the following result:

$$(4)\quad \frac{\text{Width of glaze belt 4° east 12 hours later.}}{\text{Current distance between wind-shift line and 32° isotherm.}} = 0.9$$

$$(5)\quad \frac{\text{Width of glaze belt 8° east 24 hours later.}}{\text{Current distance between wind-shift line and 32° isotherm.}} = 0.8$$

Stating the accuracy in the same manner as in the previous case we have:

For (4) with 29 cases:
- 12 agreed within 20 per cent of the mean.
- 26 agreed within 40 per cent of the mean.

For (5) with 27 cases:
- 13 agreed within 20 per cent of the mean.
- 17 agreed within 40 per cent of the mean.
- 23 agreed within 60 per cent of the mean.

The accuracy of the first in this determination is the greatest of the whole set, and, if given any relative weight, would be considered the most valuable of the five relations presented in the paper. The second is not so reliable, as might be expected, and ranks about equal with those of the preceding set.

CONCLUSION.

The need for more aerological data.—The conclusion of an investigation of this type leaves much to be desired. for the search for threads among the multiplicity of atmospheric phenomena, which, if traced, may lead to other conclusions of value, is indeed an alluring but endless effort. If fifty or a hundred such storms could be followed through, each supported by adequate observations in the upper air, there is little doubt that much could be learned which the forecasters could use with success. But each storm is a problem in itself which entails weeks of laborious tabulation and study, and, also, only those which have occurred within the last five years have even a few data from the upper air. One of the facts which this paper has brought out, however, is that *we do not have enough observations of the upper air by kites.* There are six kite stations maintained by the Weather Bureau in the eastern half of the United States. There should be at least as many more. If we were only permitted to know the depth of the under-running north wind, the vertical temperature gradient, the moisture content and strength of the southerly wind, and know them for a large number of points throughout the eastern half of the country, the forecasting of sleet and glaze—now one of the most uncertain and difficult—would be rendered relatively easy. It is needless to point out the economy of such a venture, when it is common knowledge that millions of dollars are lost or wasted through lack of preparation for these destructive emergencies. And without the upper air data, the forecasting must rest upon an unstable empirical basis.

The necessity for careful cloud observations.—The value of careful cloud observations can not be overemphasized; carelessly made observations of the kind, amount, and direction of clouds are worse than none at all, yet the average observer is likely to be less careful in this than in any part of his work. Detailed cloud observations can tell a great deal when observations by kites and pilot balloons are wanting; but where the latter are available the clouds form useful and necessary supplementary data.

The wind-shift line.—It seems worth while to mention again the importance of the wind-shift line as a factor in forecasting. Bjerknes has found it of extreme importance in forecasting precipitation; Clayton,[7] also, along similar lines, shows the importance of lines of convergence of winds as factors in forecasting precipitation, and this paper shows with clearness that the wind-shift line plays no small part in the production of sleet and glaze.

ACKNOWLEDGMENTS.

To Dr. C. F. Brooks, who not only suggested the investigation and outlined the methods, but also was willing at all times to give advice and valuable suggestions; to Mr. Willis R. Gregg, who kindly placed all the available aerological data at my disposal and made helpful suggestions; to Mr. Herbert Lyman, who assisted in the laborious tabulation of data from the original records, which form the basis for the accompanying charts; and to others, who, from time to time, displayed an encouraging interest in the study, I most gratefully acknowledge my indebtedness and express my thanks.

DEMORALIZATION OF TRAFFIC IN NEW YORK CITY BY SNOW AND SLEET.

The meteorological record of February, 1920, at New York, will long be remembered by reason of the remarkable storm—heavy precipitation which began to fall in the early morning of the 4th instant, and kept it up until the early morning of the 7th. During that period of about 75 hours, 4.45 inches of precipitation occurred. Of this amount 0.37 inch was rain; 2.11 inches of melted sleet; and 1.97 inches of melted snow. The maximum depth of snow and sleet was 17.5 inches, of which 8.8 inches were sleet and 8.7 inches [were] snow.

This is the record of the storm, as noted in Form 1001 of the New York Weather Bureau station, which caused a tie-up of traffic in the city never paralleled in spite of more excessive snowfall on two other occasions. The *Scientific American* of February 28, 1920, pages 219, 232, and 233, gives an account of the methods used to rid the streets of the immense banks of snow or of their foot-deep slushy content. Trucks were hardly able to get about with facility, traffic ways, only wide enough for a single stream of vehicles, were dug, but this resulted in great tie-ups due to efforts to pass; flame throwers, a remnant of the war, were tried, as well as another heat device, but these were so local in their results that they were impractical; the steam shovel was tried, with fair success, where the drifts were deep enough; a newly constructed snow digger was tried with great success but it was impossible to get enough of this type of machine to be of use in the emergency; finally, the fire hose was used with the greatest effect. This experience should warn all large cities where such storms are a possibility, and lead to the provision of adequate equipment for such an emergency.—*C. L. M.*

[7] Note in this REVIEW, p. 83.

TREMENDOUS SNOWSTORM IN PALESTINE, FEBRUARY 9-11, 1920.

By OTIS A. GLAZEBROOK, American Consul.

[Jerusalem, Palestine, Feb. 23, 1920.]

On the afternoon of February 9 a maid of the consulate ran into the house gleefully showing a handful of snow which she had pressed into a snowball. It was the first snow she had ever seen. As the weather had been constantly inclement since the middle of November, 1919, I supposed that this was but a snow flurry ending the former rains, as over 27 inches of rain had already fallen, this quantity being far above the average at this time of the year. In 36 hours afterwards, however, Jerusalem and the surrounding country for miles had been mantled by a snowfall which averaged on the level 40 inches, with drifts in many places reaching a height of 10 feet.

In the memory of the inhabitants of Jerusalem this was the greatest snowfall and the people were absolutely appalled by it. I recall the great blizzard of 1888 and remember many other heavy falls of snow in the United States, but none compared in possibilities of danger to this one. The locust visitation of 1915 falls into insignificance as compared with it. The people of this country being unused to such a phenomenon were totally unprepared to contend with it. There were no snow plows or even snow shovels, and if there had been the population would not have known how to handle them. All communication within the snow limit was interrupted, and the falling of the telegraph wires, the blocking of the railroad and all thoroughfares cut us off entirely from the outside world. Every store was closed. The Felahin could not bring their products to the markets. There was a shortage of bread and a dearth of wood and kerosene, and starvation and freezing faced the people. Fortunately, there is a battalion of Yorkshire troops garrisoning the city. This battalion saved the situation. At once over 700 men were at work with shovels opening the roads and streets in the city and digging out the buried population. When the stores were opened the spirit of profiteering which was already remorselessly abroad in this community—causing the prices of all necessaries, not to speak of luxuries, to increase from five to ten times their former value, having made Jerusalem in the past year possibly the most expensive place in the world, the cost of living being twice as high as in Egypt and in Syria—knew no restraint. In consequence, mob violence was imminent and the military governor was compelled to strenuously reduce the price of bread and other food commodities.

At least 40 houses in Jerusalem were crushed in by the weight of the snow, but, strange to say, the casualty list is comparatively short. When at last unfettered, the inhabitants in general proved equal to the occasion by sharing their own provisions with the poor and improvident. Conditions are now normal, the telegraph and railroad lines being in operation, stores opened, and native products coming into the market. The snow has rapidly disappeared, and except for the continued high winds and unusually cold weather one would not believe that the city had just raised itself from the dead. This blizzard will go down to history as one of the most remarkable and dangerous occurrences in the history of the Holy City, a city by no means unacquainted with extraordinary incidents.